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1809

ASTRONOMY

EXPLAINED UPON

SIR ISAAC NEWTON'S PRINCIPLES,

AND

MADE EASY TO THOSE WHO HAVE NOT STUDIED MATHEMATICS.

TO WHICH ARE ADDED,

A PLAIN METHOD OF FINDING THE DISTANCES
OF ALL THE PLANETS FROM THE SUN,

BY THE

TRANSIT OF VENUS OVER THE SUN'S DISC,

In the year 1761:

AN ACCOUNT OF MR. HORROX's OBSERVATION
OF THE TRANSIT OF VENUS,

In the year 1639:

AND OF THE

DISTANCES OF ALL THE PLANETS FROM THE SUN,

AS DEDUCED FROM OBSERVATIONS OF THE TRANSIT

In the year 1761.

BY JAMES FERGUSON, F. R. S.

Heb. xi. 3. The worlds were framed by the Word of God.
Job xxvi. 7. He hangeth the earth upon nothing.
—— 13. By his Spirit he hath garnished the heavens.

THE SECOND AMERICAN, FROM THE LAST LONDON EDITION;

REVISED, CORRECTED, AND IMPROVED,

BY ROBERT PATTERSON,

Professor of Mathematics, in the University of Pennsylvania.

PHILADELPHIA:

PRINTED FOR AND PUBLISHED BY MATHEW CAREY.

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1809.

District of Pennsylvania, to wit :

Be it remembered, That on the thirteenth day of February, in the thirtieth year of the Independence of the United States of America, A. D. 1806, Mathew Carey, of the said District, hath deposited in this office, the title of a book, the right whereof he claims as Proprietor, in the words following, to wit:

"Astronomy explained upon Sir Isaac Newton's Principles, and made easy to those who have not studied Mathematics. To which are added, a plain method of finding the distances of all the planets from the sun, by the transit of Venus over the sun's disc, in the year 1761: an account of Mr. Horrox's observation of the transit of Venus, in the year 1639: and of the distances of all the planets from the sun, as deduced from observations of the transit in year 1761. By James Ferguson, F. R. S.

Heb. xi. 3. The worlds were framed by the Word of God.
Job xxvi. 7. He hangeth the earth upon nothing.
——— 13. By his Spirit he hath garnished the heavens.

The first American edition, from the last London edition; revised, corrected, and improved, by Robert Patterson, Professor of Mathematics, and Teacher of Natural Philosophy, in the University of Pennsylvania."

In conformity to the Act of the Congress of the United States, intituled, "An Act for the Encouragement of Learning, by securing the Copies of Maps, Charts, and Books, to the Authors, and Proprietors of such Copies, during the Times therein mentioned," And also to the Act, entitled "An Act supplementary to an Act, entitled, 'An Act for the Encouragement of Learning, by securing the Copies of Maps, Charts, and Books, to the Authors and Proprietors of such Copies, during the Times therein mentioned,' and extending the Benefits thereof to the Art of designing, engraving, and etching, historical and other Prints."

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PREFACE

TO THE FIRST AMERICAN EDITION.

THE well-established reputation of *Ferguson's Astronomy*, renders any particular encomiums on the work, at this time, altogether unnecessary.

The numerous editions through which this Treatise has passed, and the increasing demand for it, bear ample testimony to its merit.

The Publisher submits to the candid acceptance of his fellow-citizens, this correct *American Edition;* for which he solicits, and flatters himself he shall obtain, their liberal patronage.

No cost or pains have been spared to render it worthy of this patronage. In the text, a number of typographical errors, and grammatical inaccuracies, have been corrected; and a variety of notes, explanatory or corrective of the text, which the numerous discoveries since our author's time had rendered necessary, have been occasionally subjoined.

Besides, to this edition alone there is prefixed a copious explanation of all the principal terms in astronomy, chronology, and astronomical geography, occurring in the

work, arranged in alphabetical order; with such remarks and examples interspersed, as were judged necessary for illustration: together with Tables of the periodical times, distances, magnitudes, and other elements, of all the planets, both primary and secondary, in the solar system; according to the latest observations.

This, it is presumed, cannot fail to be considered as a valuable appendage to the work—especially by the young student of astronomy: as the glossary will tend greatly to facilitate his progress, and the tables will present him with a comprehensive view of the whole science—the result of the observations and researches both of past and present times.

Philadelphia, Feb. 14th, 1806.

Explanation of the principal Terms relating to Astronomy, Chronology, and the astronomical parts of Geography; with occasional Illustrations and Remarks.

Aberration of a star, is a small apparent motion, occasioned by a sensible proportion between the velocity of light and that of the earth in its annual orbit. From this cause, every star will, in the course of a year, appear to describe a small ellipsis in the heavens, whose greater axis = 40″ and its lesser axis, perpendicular to the ecliptic, = 40″ × cos. of star's lat. (to radius 1.) In astronomical calculations, where great accuracy is required, and the place of a star concerned, a correction on account of aberration, as well as on other accounts, ought to be applied to the star's place as found in the tables. This correction may readily be found by the following theorems; in which A = the star's right ascension, D = its declination, and S = the Sun's longitude.

Theorem 1. (—1.272 cos. (A—S)) ÷ cos. D + (0.055. cos. (A + S)) ÷ cos. D = aberr. in R. A. in seconds of time.

Theorem 2.—20 cos. A. sin. S. sin. D + 18.346 sin. A. cos. S. sin D—7.964 cos. S. cos. D = aberr. in dec. in seconds of a degree: observing that the sine, cosine, &c. of all arches between 90° and 270° are to be considered as *negative*, and those of all other arches as affirmative.

When the star has south declination, let the sign of the last term in the 2d theorem be changed.

Acceleration (diurnal) of a fixed star, is the difference between the sidereal and the mean solar day, which = 3′ 55″.9 or 3′ 56″ of mean time nearly; and so much sooner will any fixed star rise, culminate, or set, every day, than on the preceding day. A planet is said to be *accelerated* in its motion, when its velocity, in any part of its orbit, exceeds its mean velocity; and this will always be the case when its distance from the Sun is less than its mean distance.

Æra, or *epoch*, any noted point of time, in chronology, from which events are reckoned, or computations made. Different nations or people make use of different epochs: as the Jews, that of the creation of the world; the christian nations, that of the nativity of Christ, A. M. 4007; the Mahometans, that of the Hegira, or flight of Mahomet from Mecca, A. D. 622; the ancient Greeks, that of the Olympiads, commencing B. C. 776; the Romans, that of the building of Rome, B. C. 752; the ancient Persians and Assyrians, that of Nabonasser, &c.

Altitude of a celestial body, is its elevation above the horizon, measured on the arch of an azimuth-circle intercepted between the body and the horizon. The *apparent* altitude, or that measured by an instrument, requires to be corrected in order to obtain the *true* altitude—1. by subtracting the refraction; 2. by adding the parallax; 3. by subtracting the dip corresponding to the height of the observer's eye above the surface of the earth; and 4. when the lower or upper limb of the sun or moon is observed, by adding or subtracting the apparent semidiameter.

Altitude, meridian, is that of a body when on the meridian.

Amplitude of a celestial body, is an arch of the horizon intercepted between the east or west points thereof, and that point where the body rises or sets. The true amplitude of a body may be found by the following proportion:

Rad : cos. lat. : : sin. dec. : sin. amp. which will be of the same name (north or south) with the declination.

The difference between the *true*, and the *magnetic* amplitude of a body, or that observed by a compass furnished with a magnetic needle, will be the *variation* of the compass.

Angle, is the inclination of two converging lines meeting in a point, called the *angular* point. A *plane* angle is that drawn on a plane surface. The measure of a plane angle is the arch of a circle comprehended between the lines including the angle, the angular point being the centre. A spheric angle is that formed by the intersection of two great circles on the surface of a sphere. The measure of a spheric angle is the arch of a great circle comprehended between the two arches including the angle, the angular point being its pole. A *right* angle is one whose measure is an arch of 90°. An *acute* angle is one less than 90°. An *obtuse* angle, one greater than 90°.

Anomaly is the angular distance of a planet from its aphelion. It is distinguished into *true*, *eccentric*, and *mean*. *True anomaly* of a planet, is the angle at the sun or focus of the elliptical orbit, formed by the line of apses and radius vec-

tor. *Excentric anomaly*, is the angle at the centre of the elliptical orbit, formed by the line of apses and a line drawn to the point in which an ordinate passing through the planet's true place in its orbit, meets the circumference of a circle, described on the line of apses as a diameter.

Mean anomaly, is a sector of the elliptical orbit over which the radius vector has passed, from the aphelion to the place of the planet in its orbit; and is proportional to the time of description.

Antarctic circle. See *Arctic* circle.

Antipodes, those who inhabit parts of the earth diametrically opposite to each other.

Anticipation of the equinoxes or seasons, the excess of the civil Julian year of 365d. 6h. above the solar tropical year of 365 days 5 hours 48 minutes 48 seconds. This constitutes the difference between the Julian and Gregorian calendars, or old and new styles.

Aphelion, is that point of a planet's orbit which is at the greatest distance from the sun.

The *places* of the aphelia of the several planets are all different, and have each a small progressive motion, occasioned by the mutual attractions of the planets on each other.

Apogee, is that point of the moon's orbit which is at the greatest distance from the earth. This term is also frequently applied to the sun, to signify that point in which he is at the greatest distance from the earth.

Apses or *apsides*, are the extremities of the greater axis of the planets' elliptical orbits: the axis itself being called *the line of the apses*.

Arctic circle, is a small circle parallel to the equator, and at the same distance from the north pole that the tropics are from the equator. A circle similarly situate round the south pole, is called the *antarctic* circle. These are also frequently termed the *north-polar*, and *south-polar* circles, respectively.

Ascension of a celestial body, is an arch of the equator, reckoned from west to east, and intercepted between the equinoctial point Aries, and that point which rises with the body. This is distinguished into *right*, and *oblique* ascension, according to the angle in which the equator cuts the horizon.

Aspect, is a term applied to signify the situation or apparent distance, in longitude, of any two celestial bodies in the zodiac, from one another, and is particularly denominated, and designated by appropriate characters, according to this distance—as conjunction ☌, sextile ✱, quartile □, trine △, opposition ☍, and some others, which see.

Asteroids, star-like bodies, a term of recent invention, and applied to three small bodies lately discovered in the solar system, between the orbits of Mars and Jupiter. Their orbits are considerably more excentric than that of any of the other planets; though their elements are still but imperfectly ascertained.—See note subjoined to the Table of the solar system, page 73.

Astronomy, is that science which explains and demonstrates the phenomena of the heavens.

Atmosphere, usually termed *the air*, is that transparent elastic fluid which surrounds the earth. It is indispensably necessary to animal and vegetable life, combustion, and many other functions in nature. The atmosphere being a perfectly elastic, compressible, and ponderous fluid, its density must decrease upwards, in a geometrical ratio, of the heights taken in arithmetical ratio. The whole weight of any column of the atmosphere, on the surface of the earth, is found, by experiment, to equal, in a mean state, that of a column of mercury of an equal base and about 30 inches high; that is, about 15 pounds avoir. on every superficial inch. The planets, if not the sun and fixed stars, are all probably furnished with similar atmospheres.

Attraction, is that power, either continually exerted by the Deity, according to a fixed law, or by him communicated to matter; by which all bodies, or particles of bodies, whether in contact, or at a distance, adhere, or tend towards each other. Attraction, according to the manner or circumstances of its operation, is commonly distinguished into that of *gravity*, that of *cohesion*, that of *electricity*, &c.

Axis of a planet, is that imaginary line passing through its centre, round which it performs its diurnal rotation.

Azimuth of a celestial body, is an arch of the horizon intercepted between the meridian of the place and the azimuth-circle passing through the body. The true azimuth of a body may readily be calculated by the resolution of a spheric triangle; and then the difference between this, and that observed by a compass furnished with a magnetic needle, will be the *variation* of the compass.

Azimuth-circles, are those great circles of the sphere which pass through the zenith and nadir, and consequently cross the horizon at right angles.

Barometer, is an instrument for measuring the weight of a superincumbent column of the atmosphere, at any given time and place. It is commonly made of a long glass tube, of a moderate bore, open at one end; which being filled with well-purified mercury is inverted, with the

open end downwards, into a bason, of the same fluid. The mercury in the tube will then subside, leaving a vacuum in the upper part of the tube; and the height of the column of mercury in the tube, thus sustained by the pressure of the atmosphere on the surface of the mercury in the bason, will be a just measure of its weight.

It is found by experiment that the height of the column of mercury is not always the same in the same place, but varies generally between 28 and 31 inches, on the surface of the earth. The barometer has been applied with success to the measuring of accessible altitudes. For this purpose let the height of the mercury in a barometer, both at the bottom and top of the eminence or depth to be measured, be observed as nearly as may be at the same time. Also observe the temperature of the air by thermometers both attached to the barometers, and at a distance from them, in the shade. Then let the column of mercury in the colder barometer be increased by its 9600th part for every degree of difference in the two attached thermometers (Fahr. scale). Subtract the common logarithm of the less column of mercury from that of the greater, and the difference multiplied by 10000 will be the alt. nearly, in fathoms. For a correction apply, by addition or subtraction, one 435th part of the above alt. for every degree of the mean temperature of the two detached thermometers above or below 31 degrees, and the result will be the true alt.

Bissextile, a year consisting of 366 days, by adding a day to the month of February every 4th year. This day was by Julius Cæsar appointed to be the 24th of March (called by the Romans the 6th of the calends) which being reckoned *twice*, the year was on this account termed *bissextile*. This year is, on another account, called *leap-year*.

Calendar, is a table, almanac, or distribution of time, suited to the several uses of society.

Various calendars have been adopted by different nations in different ages of the world.—The Roman calendar, as corrected and established by Julius Cæsar, and thence called the Julian calendar, made the year to consist of 365¼ days; viz. three years each containing 365, and the 4th 366. But as the solar year actually falls short of the Julian by about 11 minutes, Pope Gregory XIII, in 1582, reformed this calendar, by striking out the surplus days that the seasons had then got a-head of the calendar; (viz. 10 days) and ordering that, in future, 3 days should be stricken out of every 400 years of the Julian account, by calling every centurial year not devisible by 4 (as 1700,

1800, 1900, 2100, &c.) a common year, instead of a leap-year. The year is divided into 12 calendar months, viz 7 of 31 days, 4 of 30, and 1 of 28 or 29.

Central forces, are those by the influence of which the planets and comets perform revolutions round their centres of motion, and are retained in their orbits. Those forces are of two kinds, viz the centrifugal, and the centripetal.

Centrifugal or projectile force, may be considered as a *single impulse*, given by the Creator, and which, agreeably to the laws of motion, would carry the body with a uniform velocity, in a rectilineal direction.

Centripetal force, or force of gravity, may be considered as a continually-operating influence, urging the body down towards the centre of motion: and according to the proportion between these two forces the body will describe a circular, or an elliptical orbit.

Chronology, is that science which treats of time, comprehending its remarkable æras or epochs, divisions, subdivisions, and measures.

Circle, is a plane figure bounded by a uniformly-curved line called the circumference, every part of which is equally distant from a certain point within the same, called the *centre*. *Diameter* is a right line passing through the centre, and terminated on each side by the circumference. *Radius*, or semidiameter, is the distance from the centre to the circumference.

Circles of the sphere are of two kinds—great, and small. *Great circles*, are those which divide the sphere into two equal parts; the chief of which are, the equator, the ecliptic, meridians, horizon, azimuth-circles, and circles of celestial longitude. *Small circles*, are those which divide the sphere into two unequal parts; the chief of which are, parallels of altitude and of depression, parallels of terrestrial, and parallels of celestial latitude.

Circles of celestial longitude, are those great circles of the sphere which cross the ecliptic at right angles.

Circum-polar stars, are those which appear to perform daily circuits round the pole, without rising or setting; and such are all those whose polar distance does not exceed the latitude of the place.

Colures, are those two meridians which pass through the equinoctial and solstitial points of the ecliptic, and are hence distinguished into the *equinoctial* and *solstitial* colures.

Comets, are certain bodies in the solar system, moving in very excentric orbits, in various planes and directions, and visible but for a short time when near their perihelia; and then generally appearing with a lucid tail or train

of light, on the side of the comet opposite to the sun. Frequently, however, comets are seen without this lucid train ; the body or nucleus being surrounded with a bearded or hairy-like atmosphere. The whole list of comets that have been hitherto observed amounts to upwards of 500 ; of which about 170 have been observed with accuracy, and the elements of their orbits computed.

Conjunction, is that aspect in which two celestial bodies, in the zodiac, have the same longitude.

Constellation,—this term is applied to any assemblage or number of neighbouring stars in the heavens, which astronomers have classed together under one general name. They are generally designated by the names and figures of some living creatures, and thus delineated on the celestial globe or atlas. The number of constellations, according to the ancients, was 48, viz. 12 near the ecliptic, called the 12 signs of the zodiac, 21 on the north side of the zodiac, and 15 on the south side. Modern astronomers, by forming new constellations out of such stars as were not included in the above, have increased the number to about 70—The several stars in each constellation are distinguished either by letters of the alphabet, or by numbers : and some few by proper names; as, Aldebaran, Castor, Pollux, &c.

Crepusculum or twilight-circle, is a circle of depression, 18 degrees below the horizon ; for, it is found by observation that when the sun crosses this circle, before rising, or after setting, twilight begins or ends. This is occasioned by the rays of light from the sun being refracted and reflected by the earth's atmosphere.

Culmination of a star, is the point of its greatest elevation above the horizon, or where it crosses the meridian.

Cusps, the horns of the moon, or any other planet, when less than half its illuminated part is visible.

Cycle, is any certain period of time in which the same circumstances, to which the cycle has a reference, regularly return. The most noted chronological cycles are—

1. *The cycle of the sun*, a period of 28 years, after which the same day of the month will happen on the same day of the week, as in the same year of a former cycle.

2. *The Metonic* or *lunar cycle*, a period of 19 years, after which the change, full, and other phases of the moon, will happen on the same days of the month, as in tho same year of a former cycle.

3. *The cycle of Indiction*, a period of 15 years, instituted by Constantine A. D. 312, probably as a stated period of

levying a certain tax, and afterwards used as a civil epoch among the Romans.

Note, the 1st year of the Christian æra was the 1st after leap-year, the 9th of the solar cycle, the 1st of the lunar cycle, and the 312th of the Christian æra, was the 1st of the Roman Indiction. Hence rules may be easily deduced for computing what year of any of these cycles, corresponds to any given year of the Christian æra.

Day, a portion of time measured by the apparent revolution of the sun, moon, or stars, round the earth. The day is variously distinguished and denominated, according to circumstances, as follows :—

1. An *artificial day*, is the interval of time between sun-rising and sun-setting, and thus contradistinguished from *night* which is the interval between sun-setting and sun-rising.

2. A *natural day*, includes both the artificial day and the night.

3. An *apparent solar day*, is the time in which the sun appears to make one complete revolution round the earth. These days, owing to sundry causes, (see *equation of time*) are not all of the same length, but continually varying.

4. A *mean solar day*, is an exact mean of all the apparent solar days in the year—Or it is that measured by a well-regulated time-piece.

5. A *Lunar day*, is the time in which the moon appears to make one complete revolution round the earth; and exceeds a solar day about ¾ of an hour.

6. A *sidereal day*, is the time in which any fixed star appears to make a complete revolution, and is 3m. 55″.9 less than a mean solar day.

The day, in civil reckoning, begins among different nations at different times.

1. Among most of the ancient eastern nations, and some of the modern, it begins at sun-rising.

2. Among the ancient Athenians and Jews, the eastern parts of Europe, and the modern Italians and Chinese, it begins at sun-setting.

3. With the ancient Arabians, and still with astronomers, it begins at noon.

4. Among the ancient Egyptians and Romans, the Americans, and the greater part of Europeans, it begins at midnight.

Declination of a celestial body, is an arch of the meridian passing through the body, and intercepted between it and the equator; and is north or south according as the body is north or south of the equator.

Degree, the 360th part of the circumference of any circle. Or the 90th part of a right angle.

Dial, or *sun-dial*, is a delineation of the meridians of the sphere, on a plane, in such a manner that the shadow of a gnomon or stile, placed with its edge parallel to the Earth's axis, may point out the hour of the day. Dials are particularly denominated from the planes on which they are drawn; as horizontal, equatorial, &c.

Digit, the 12th part of the apparent diameter of the sun or moon. The quantity of an eclipse is generally estimated by the digits of the luminary's diameter eclipsed.

Dip, the depression of the visible, below the true horizon, which will be more or less according to the height of the eye. The dip corresponding to any given height of the eye may be very readily, and very accurately, found by the following theorem.

$d = \sqrt{h} - \frac{1}{20}\sqrt{h} + 1''$; in which $h =$ height of eye in feet, and $d =$ the dip in minutes and parts, of a degree: thus for 16 feet the dip, per rule $= 4' - .2' + 1'' = 3'\,49''$.

Direct motion of a planet, in its orbit, is that by which it appears to the observer to move according to the order of the signs. To a spectator in the sun, the planetary motions would always appear direct. To a spectator in the earth, the motions of Mercury and Venus will appear direct when they are in the superior or opposite parts of their orbits; and the motions of the other planets will appear direct when the earth is in the opposite part of its orbit with respect to them

Disc, the body or face of the sun or moon as it appears to a spectator on the earth; or of the earth, as it would appear to a spectator in the moon.

Dominical letter. In the Roman calendar, it was customary to prefix the first 7 letters of the alphabet to the several days of the week throughout the year, always beginning the year with the letter A. The letter, then, that was prefixed to the Sundays (Dominici dies) throughout the year, was called the Dominical letter. This may be found for any year of the Christian æra, by the following rule.

Divide the centuries by 4, subtract twice the remainder from 6, and to what remains add the odd years and their 4th part, rejecting fractions, divide the sum by 7, and then the remainder taken from 7 will leave the *number* of the Dominical letter in the alphabet. Thus for the year 1806 the Dominical letter will come out 5 = E.

In a leap-year, the letter thus found will be the Dominical letter till the 23th of Feb. and the preceding one will be the Dom. let. from that time till the end of the year.

Earth, the third planet in order from the sun; at the distance of about 95 millions of miles; furnished with one moon.

Eclipse. When any secondary planet passes through the shadow of its primary, it is said to be eclipsed; as the moon by the shadow of the earth, or any of Jupiter's satellites by his shadow. But when the shadow of a secondary planet falls on its primary, then, with respect to that part of the primary on which the shadow falls, the sun is said to be eclipsed.

Ecliptic limit, is a certain distance from the node of the secondary's orbit, beyond which no eclipse can happen. This limit with respect to a solar eclipse is about 17°. and with respect to a lunar eclipse, about 12°.

Ecliptic, a great circle of the sphere in the plane of which the earth performs its annual revolution round the sun.

Ellipse or *ellipsis*, a plane curvilineal figure, which may be described round two centres thus.—Take a thread of any determinate length, tie its two ends together, and throw the loop round two pins stuck into a plane board—then moving round a pencil, or the like, within the loop, so as to keep it always tight, the curve described will be an ellipsis.—The two central points are called the *foci* of the ellipsis; a right line passing through the two foci, and terminated by the curve on each side, is called the *transverse* axis or diameter, and one bisecting this at right angles is called the *conjugate*.

Elongation of a planet, (generally applied to Mercury and Venus) their angular distance from the sun as seen from the earth.

Embolismic, or *intercalary*, a term applied to a lunar month occasionally *thrown in* to bring up the lunar to the solar years.—It is also applied to the 29th of February, thrown in every 4th year to make the civil years correspond with the solar.

Emersion, the end of an eclipse or of an occultation.

Epact, the excess of solar time above lunar. In the Gregorian calendar it is the moon's age at the beginning of the year, which may be found by the following rule, till the year 1900.

Subtract 1 from the Golden number, multiply the remainder by 11, and the product, rejecting the 30's, will be the epact.

Epoch. See Æra.

Equation of time, the difference between apparent, and mean solar time. This arises from two causes, viz. the elliptical figure of the earth's orbit in which the diurnal arches will of consequence be unequal; and the inclination of the the ecliptic to the equator, whence equal arches of the former, in which the earth moves, will not correspond to equal arches of the latter, on which time is measured.

Equator, that great circle which cuts the axis of rotation at right angles.

Equinoctial points, the beginning of the signs Aries and Libra, those two points of the ecliptic in which it crosses the equator: the former being called the *vernal*, and the latter the *autumnal*, equinoctial point.

Equinoxes, the times when the sun appears to enter the equinoctial points; viz. the 21st of March, and 22d of September.

Excentricity, or eccentricity, of a planet's orbit, is equal to half the distance between the two foci of the elliptical orbit.

Focus, *foci*. See Ellipsis.

Frigid zones, those round the poles, bounded by their respective polar circles.

Geocentric place of a planet, is its place, (generally expressed in latitude and longitude, or right ascension and declination) as it appears from the earth.

Globes (artificial) small spheres of paste-board, or the like, on one of which (called the terrestrial globe) are drawn the principal circles of the sphere, together with the several continents, islands, &c. of the earth, in their relative situations and magnitudes. On the other, (called the celestial globe) besides the circles of the sphere, are inserted all the visible fixed stars, distributed into their respective constellations. *The use of the Globes*, explains the manner of solving geographical and astronomical problems, by means of artificial globes.

Golden number, is the year of the lunar cycle, increasing annually by unity from 1 to 19.

Gravity, that species of attraction which takes place between bodies at a distance from each other, and by which, if not otherwise prevented, they would mutually approach each other, with a continually-accelerated velocity. Gravity is directly proportional to the quantity of matter, and inversely, to the square of the distance.

Heliocentric place of a planet, is its place in the heavens, as if viewed from the sun.

Herschel, or *Georgium Sidus*—the 7th primary planet in order from the sun, at the distance of about 1800 millions of miles. It is furnished with 6 satellites.

Horizon, that great circle of the sphere which, extended to the heavens, is the boundary of our vision. It is usually distinguished into sensible or visible, and rational or true.

Hour, the 24th part of a natural day.

Horary angle of a celestial body, an angle at the pole of the equator, included between the meridian of the place and that passing through the body.

Immersion, the beginning of an eclipse, or of an occultation.

Inclination of the axis of a planet, the angle which it makes with the axis of the plane of its orbit.

Inclination of the orbit of a planet, the angle in which it crosses the ecliptic.

Indiction, (Roman). See Cycle.

Jupiter, the fifth primary planet from the sun, at the distance of about 490 millions of miles. It is the largest in the system, and is furnished with four satellites.

Latitude of a place on the earth, its distance from the equator, measured on the meridian of the place.

Latitude of a celestial body, its distance from the ecliptic, measured on a circle of celestial longitude passing through the body.

Leap-year, one of 366 days, occurring every 4th year, and so called, because in that year the Dominical letter falls back two letters, or *leaps* over one. See Bissextile.

Libration of the moon, a small apparent libratory motion, arising chiefly from her equable rotation round her axis, combined with her unequal motion in her orbit.

Longitude of a place on the earth, an arch of the equator intercepted between the prime meridian, and that passing through the place, and is denominated east or west, according to its situation with respect to the prime meridian.

Longitude of a celestial body, an arch of the ecliptic, reckoned according to the order of the signs, from the equinoctial point Aries to the circle of celestial longitude passing through the body.

Lunar cycle. See Cycle.

Mars, the fourth primary planet from the sun, at the distance of about 144 millions of miles.

Meridians, great circles crossing the equator at right angles.

Meridian of the place, that passing through the north and south points of the horizon.

Midheaven, that point of the ecliptic, or of the equator, which is in the meridian.

Minute, the 60th part of an hour, or of a degree.

Month, the 12th part of a year. It is variously distinguished according to circumstances, viz.

Lunar illuminative month, the time between the first appearance of one new moon, and of the next. The ancient Jews, with the Turks and Arabs, reckon by this month.

Lunar periodical month, the time in which the moon appears to make a revolution through the zodiac = 27 d. 7 h. 43 m. 8 s.

Lunar synodical month, or *lunation*, the time between one new moon, or conjunction of the sun and moon, and the next: at a mean = 29d. 12h. 44m. 3s. 11t.

Solar month, the 12th part of a solar tropical year = 30d. 10h. 29m. 5s.

Calendar months, those made use of in the common reckoning of time, as in Almanacs or Calendars.

The judicial month, consists of 4 weeks or 28 days.

Moon, the satellite or secondary of the Earth, at the distance of about 240 thousand miles.

Nadir, the lower pole of the horizon.

Nodes of a planet's orbit, those two points in which it crosses the ecliptic. That in which the planet passes from the south side of the ecliptic to the north, is called its *ascending node* or *dragon's head* ☊, and the opposite point, its *descending node*, or *dragon's tail* ☋. The nodes of all the planets' orbits have a slow retrograde motion, occasioned by their moving in different planes, and their mutual attraction on each other.

Nonagesimal, that point in the ecliptic which is 90° from the horizon.

Nutation of a star, a small apparent motion, occasioned by the variable attraction of the sun and moon on the spheroidal figure of the earth; by which the axis is made to revolve with a conical motion, the extremities or poles describing in 18y. 7m. the lunar period, or revolution of the moon's nodes, a small ellipse whose transverse diameter = 19″.1 and conjugate = 14″.2. The correction of the right ascension and declination of a star arising from this cause may be readily found by the following theorems: in which A = the right ascension of the star (per table), D = its declination, and N = the longitude of the moon's ascending node.

Th. 1. — 8″.3 cos. (N — A) tan. D — 1″.25 cos. (N + A) tan. D — 16″.25 sin. N. = the nutation in Rt. as. in seconds of time.

Th. 2. $\pm 9''.55$ cos. N. sin. A $\mp 7''.05$ cos. A sin. N = the nutation in declin. in seconds of a degree. The upper signs are to be used when the star has north dec. and the under signs when it has south dec. See Aberration.

Oblique ascension of a celestial body, that point of the equator which rises at the same time with the body in an oblique sphere.

Obliquity of the ecliptic, the angle in which the ecliptic crosses the equator

Occultation of a star, the moon's passing between the star and the observer, and thereby, for a time, hiding it from his sight.

Olympiads. Games celebrated by the Greeks every 4 years. See Æra.

Opposition, that aspect in which the difference of longitude of the two bodies is 180°.

Orbit of a planet, the path in which it revolves round its centre of motion. The orbits of all the planets, whether primary or secondary, are elliptical, though of but small excentricity; and all (with the exception of Herschel's satellites) nearly in the plane of the ecliptic, or earth's orbit.

Parallax of a celestial body, is equal to the angle at the body, subtended by a semidiameter of the earth terminating in the place of the observer. Hence the horizontal parallax of a body will be the greatest, and in the zenith it will entirely vanish. The fixed stars, from their immense distance, have no sensible parallax.

Parallax of the earth's annual orbit, at a planet, is the angle at that planet subtended by the distance between the earth and sun.

Penumbra, a faint or imperfect shade, observed in eclipses, and occasioned by a partial interception of the sun's light.

Perigee, that point of the moon's orbit which is nearest to the earth. The term is sometimes applied to signify that point in which the sun is nearest to the earth.

Perihelion, that point of a planet's orbit which is nearest to the sun.

Periodical time of a planet, that in which it performs a complete revolution round its centre of motion.

Perioeci, such as live in opposite points of the same parallel of latitude.

Periscii, those whose shadows turn quite round during the day, the sun not setting—and such, at certain times of the year, are the inhabitants of the frigid zones.

Phases of a planet, the various appearances of the visible illuminated part, as horned, half illuminated, gibbous, full.

Planets, bodies in the solar system, which revolve in orbits nearly circular, and all nearly in the same plane. They are distinguished into *primary*, and *secondary*.

The *primary planets*, revolve round the sun as their centre, and the secondaries, round their respective primaries as their centres.

The table at the end of this Glossary contains a correct synopsis of the distances, magnitudes, periods, and all the other important elements of the several planets, both primary and secondary, in the solar system, according to the latest observations. The sun's horizontal parallax, as determined from the transit of Venus in 1769, being $8''\frac{1}{2}$.

Poles of any great circle of the sphere, two opposite points in the surface of the sphere, each 90 degrees distant from the circumference of the given circle.

Precession, *recession*, or *retrocession* of the equinoxes, a slow motion of $50''\frac{1}{4}$ per year, by which the equinoctial points of the ecliptic are carried backwards from east to west, and consequently the ecliptical stars carried forwards from west to east.

This motion is occasioned by the attraction of the sun and moon, on the matter of the earth accumulated at the equator by its diurnal rotation.

Primary planets, those bodies in the solar system which revolve round the sun as their centre of motion, in orbits nearly circular.

Prime vertical, that azimuth-circle which passes through the east and west points of the horizon.

Quadrature, or *quartile*, that aspect in which the bodies have 90°. difference of longitude.

Radius vector of a planet, the distance from the planet, in any given part of its orbits, to the centre of motion.

Refraction of a celestial body, the angle in which the rays of light coming from the body, are bent downwards from their right course in falling obliquely upon, and passing through, the earth's atmosphere. This is greatest in the horizon, and entirely vanishes in the zenith.

Retrograde motion of a planet, that by which it appears to the observer to move contrary to the order of the signs. To a spectator on the earth, Mercury and Venus will appear retrograde when they are in the inferior or nearer part of their orbits, and all the other planets will appear

retrograde when the earth is in the nearer part of its orbit with respect to them.

Satellites, or secondary planets, or moons, those smaller bodies in the solar system which regard the primaries as their centres of motion.

Saturn, a primary planet, the 6th in order from the sun, at the distance of about 900 millions of miles. It is furnished with a stupendous double ring and 7 satellites.

Second, the 60th part of a minute, whether of time or of a degree.

Sextile, that aspect where the difference of longitude of the two bodies = 60°.

Sign of the ecliptic, an arch of 30°, or the 12th part of the whole circle.

Signs of the zodiac, twelve constellations, distributed through the zodiac, and nearly at equal distances. The vernal equinoctial point was formerly in the constellation Aries, but owing to the precession of the equinoxes it is now in the constellation Pisces; yet the *artificial* signs continue to be called by their former names. The equinoctial points being still denominated Aries and Libra, and the solstitial points, Cancer and Capricorn.

Solar system, comprehends the sun, the centre of the system, the primary planets, the secondary planets, and the comets.

Solar cycle.—See Cycle.

Solstices, the times when the sun enters the two solstitial points of the ecliptic, viz. the 21st of June, the time of the northern solstice, and the 22d of December, that of the southern solstice. These with relation to the northern hemisphere, are frequently denominated the summer, and winter, solstices, respectively.

Solstitial points of the ecliptic, those opposite points in which the sun has the greatest declination, viz. the beginning of the sign Cancer in the northern hemisphere, and the beginning of the sign Capricorn, in the southern.

Sphere, in a geometrical sense, is a solid contained under a uniformly-curved surface, every point of which is equally distant from a certain point within the same, called the centre. This term is applied to the several celestial bodies, as they are probably all nearly of this figure. It is also applied to the apparent concave surface of the heavens, and is then called the *celestial sphere*.

The sphere, in geography and astronomy, is frequently distinguished by the epithets right, oblique, or parallel, according to the position of the equator and horizon:

A right sphere, is that in which the equator cuts the ho-

rizon at right angles, and such is the case to an inhabitant at the equator. In this sphere the lengths of the days and nights are always equal.

An oblique sphere, is that in which the equator cuts the horizon at oblique angles; and such is the case to any inhabitant north or south of the equator. In this sphere the lengths of the days and nights are always varying—the variation being greater, the greater the latitude.

A parallel sphere, is that in which the equator is parallel, or rather coincident, with the horizon; and such is the case to an inhabitant at either pole. In this sphere, the sun will be six months successively visible, and six invisible.

Spheroid, a solid which may be conceived as generated by the rotation of an ellipsis round its tranverse or conjugate diameter. In the former case, the spheroid is said to be *prolate*, and in the latter, *oblate*. The figure of the earth, and perhaps that of most of the other planets, is nearly that of an *oblate spheroid*. This arises from their rotatory motion round their axes, by which, the attraction at the surface is continually diminished from the poles to the equator, by the continued increase of the centrifugal force; and thus, the equatorial diameter becomes greater than the polar. It follows from this figure, that the length of the degrees of latitude gradually increase from the equator to the poles. To this figure of the earth we are to ascribe many of the apparent irregularities in the motions of the celestial bodies: as, the precession of the equinoxes. the nutation of the stars, &c.

Stars, or *fixed stars*, luminous bodies, at an immense distance, appearing in all parts of the heavens. They all probably resemble the sun in matter and in magnitude, and are each the centre of a system, similar to the solar system. They are said to be *fixed* because they constantly preserve, very nearly, the same relative position to each other. Besides the small apparent motion of the stars arising from aberration, and nutation, and the precession of the equinoxes; in some of them there has been discovered a very slow (indeed) *proper* motion. Whence it is conjectured that not only the bodies belonging to the innumerable systems of stars are in motion round their respective centres, but that all the systems of bodies in the universe are themselves in motion round some common centre—and that thus they are prevented from approaching each other, which, from their mutual attractions, they must otherwise do.

Stationary. This term is applied to a planet, when, for some time, it appears to a spectator to occupy the same place in the zodiac. To a spectator in the sun, the planets' motions would always appear direct; and that they ever appear otherwise to a spectator on the earth, is owing to its own motion, and being placed out of the centre of the system. To such a spectator, Mercury and Venus will appear stationary when at their greatest elongation; and all the other planets will appear stationary when the earth is at its greatest elongation with respect to them.

Style, the particular manner of counting time. It is distinguished into old and new.

Old style, is that which follows the Julian calendar.

New style, is that which follows the Gregorian calendar. See Calendar. In the year 1800 the latter was 12 days ahead of the former, and in every centurial year not divisible by 4, the difference will be increased 1 day.

Systems of the Universe. Of these there are 3 noted ones in the history of astronomy, viz. the *Ptolemean system*, advocated by many of the ancient philosophers. According to this, the earth occupies the centre of the universe, and is at rest; while all the celestial bodies revolve round it from east to west, every 24 hours. The *Tychonean system*, invented by Tycho Brahe, a noted Danish Astronomer, born A. D. 1546. According to this system, the earth, as in the Ptolemean system, is placed in the centre of the universe, the moon revolving round the earth as her proper centre, while the sun, with all the other planets moving round him as satellites, revolve also round the earth.

Copernican system, maintained by many of the ancients, particularly by Pythagoras, revived by Copernicus a native of Thorn in Prussia (born 1473), and demonstrated by Sir Isaac Newton. According to this it is demonstrated that the sun is the centre of the planetary system; the primary planets revolving round him in their annual orbits, and the secondaries round their respective primaries. That the orbits both of the primary and secondary planets are all nearly circular, though in fact elliptical; the sun, or primary, being placed in one of the foci of the respective orbits. That they all lie nearly in the same plane. That all the planets revolve nearly in the same direction, the square of their periodical times being directly proportional to the cubes of their mean distances from the centre of motion. That the earth, and perhaps most, if not all the other primary planets,

perform a diurnal rotation round their axes; and that the moon, or satellite of the earth, as well as perhaps all the other satellites, constantly present the same face towards their primaries. That the inclination of the axis of rotation to the plane of the orbit is different in different planets; and that thus they experience a difference in their diversity of seasons.

Syzigy. This general term is applied both to signify the conjunction and opposition of a planet with the Sun.---It is however chiefly used in relation to the moon.

Tides, a periodical alternate motion or flux and reflux of the waters of the sea.

These are caused chiefly by the attraction of the moon, though in part by that of the Sun also; and accordingly there are two tides of flood (and consequently two of ebb) in the course of every lunar day. The apex of one of the tides of high water is immediately under, or rather about 45° eastward of, the moon; and the other, diametrically opposite. These are produced by the unequal attractions of the moon on the part of the earth nearest to her, on the centre of the earth, and on the part farthest from her (attraction decreasing inversely with the square of the distance.) One tide therefore is produced by a redundancy of attraction, drawing the waters up towards the moon, and the opposite tide, by a deficiency of attraction, leaving, as it were, the waters behind. When the sun and moon are in conjunction or opposition, the tides, being then produced by their joint influence, are higher than usual, and hence called *spring-tides*; but when these bodies are in quadrature, the tides, being produced by the difference of their influence, are lower than usual, and hence called *neap-tides*.

Time is measured by the apparent motion of the celestial bodies; and is variously distinguished: thus—

Apparent solar time, is that measured by the apparent motion of the sun; and hence the apparent solar time from noon, is equal to the sun's horary angle reduced to time, at the rate of 15° to the hour.

Mean solar time, is that shewn by a true time-piece, going with an equable motion throughout the year.

Sidereal time, is that measured by the apparent equable motion of the stars.

Lunar time, that measured by the apparent motion of the moon. See Day.

Transit of an inferior planet (Mercury or Venus) over the sun's disc, is when the planet, at the time of an inferior conjunction, passes between the sun and the ob-

server. This will only happen when the planet, at the time of this conjunction, is in or near its node.

Trine, an aspect where the bodies are at the distance of $\frac{1}{3}$ of the ecliptic or 120°.

Twilight. See Crepusculum.

Venus, the second primary planet from the sun, at the distance of about 68 millions of miles.

Year, a period of time generally considered as comprehending a complete revolution of the seasons. The year is variously distinguished, viz.

1. *Tropical Solar year*, the time in which the sun appears to perform a complete revolution through all the signs of the zodiac = 365d. 5h. 48m. 48s.

2. *Sidereal year*, the time in which the sun appears to revolve from any fixed star to the same again = 365d. 6h. 9m. 17s. The difference between the tropical and sidereal year (20m. 29s.) is the time of the sun's apparent motion through 50″$\frac{1}{4}$, the arch of annual precession.

3. *Lunar astronomical year*, consists of 12 lunar synodical months = 354d. 8h. 48m. 38s. and therefore 10d. 21h. 0m. 10s. less than the solar year—a difference which is the foundation of the epact.

4. *The common lunar civil year*, consists of 12 lunar civil months, = 324 days.

5. The *embolismic* or *intercalary lunar year*, consists of 13 lunar civil months = 384 days.

6. The *common civil year*, contains 365 days, divided into 12 calendar months.

7. Bissextile or leap-year, containing 366 days. See calendar.

Zenith, the upper pole of the horizon.

Zenith-distance of a celestial body, its distance from the zenith, measured on the azimuth-circle passing through the body, and is equal to the complement of the altitude to 90°.

Zodiac, a zone or broad circle in the heavens including all the planets, and extending about 10°. on each side of the ecliptic.

Zodiacal light. a pyramidal lucid appearance, sometimes observed in the zodiac, resembling the galaxy, or milky way. It is most plainly observable after the evening twilight about the latter end of February; and before the morning twilight about the beginning of October. For at these times it appears nearly perpendicular to the horizon. This appearance is generally supposed to be occasioned by the sun's atmosphere.

Zone, in astronomical geography, is applied to a division of the earth's surface by certain parallels of latitude.

The Zones are 5 in number, viz.

1. *The torrid zone*, lying between the two tropics. It comprehends the West India Islands, the greater parts of South America and of Africa, the southern parts of Asia, and the East India Islands.

2. *The north frigid zone*, lying round the north pole, and bounded by the north polar circle. It comprehends part of Greenland, of the northern regions of North America, and a little of the northern parts of Europe and Asia.

3. *The south frigid zone*, lying round the south pole, and bounded by the south polar circle. It contains no dry land, so far as yet discovered.

4. *The north temperate zone*, lying between the torrid and north frigid. It comprehends almost the whole of North America, Europe, and Asia, with the northern part of Africa.

5. *The south temperate zone*, lying between the torrid and south frigid. It comprehends the southern part of South America, of Africa, and of the great island of New-Holland.

In the torrid zone, the sun is vertical twice a year to every part of it, and there is very little diversity in the length of the day throughout the year, the longest day varying only from 12 to about 13½ hours. In the temperate zones the sun is never vertical, and the length of the longest day varies from about 13½ to 24 hours. In the frigid zones, the length of the longest day (or time between the sun's rising and setting) varies from 24 hours to 6 months.

Table of the Planets' motions, distances, &c.

Elements	Mercury	Venus	The Earth	Mars	Jupiter	Saturn	Herschel
Periodical revolution round ☉ in days and parts.	87.969255	224.700817	365.256384	686.979579	4332.60220	10759.077213	30689.
Rotation round axis in hours and parts.		23.3667	23.9344	24.6559	9.9305	10.272	
Inclination of orbit to ecliptic in degrees and parts	7°	3°.3931	× ×	1°.85	1°.3172	2°.4986	0°.7739
Inclination of axis.		75°.	23°.4667	59°.697	4°.		
Longitude of ascending node.	45°.3452	74°.4384	× ×	47°.6439	79°.9256	111°.5394	72°.6313
Longitude of perihelion.	73°.5661	127°.7783	278°.6211	231°.4705	10°.3511	87°.1519	166°.6136
Proportional mean distance from ☉	.3871	.72333	1.	1.52369	5.20279	9.54072	19.18362
Proportion of excentricity to mean distance.	.20551	.00688	.01681	.09309	.04808	.05622	.04688
Proportion of diameters.	.4012	.9593	1.	.5199	10.862	9.983	4.454
Proportion of densities, water being 1.	9.1696	5.7375	4.5	3.2814	1.161	.4702	.2701
Proportion of polar to equatorial diameters.			229:230	15:16	13:14	10:11	

TABLE OF THE SATELLITES.

	The Earth's.		Jupiter's.		Saturn's.		Herschel's.	
Satellites.	Period. revol. in days.	Dist.	Period. revol. in days.	Dist.	Period. revol. in days.	Dist.	Period. revol. in days.	Dist.
1	29.3216	60.5	1.76914	5.6973	0.94271	3.08	5.8923	12.5
2			3.55118	9.0659	1.37024	3.952	8.708	16.5
3			7.15455	14.4616	1.88780	4.893	10.966	19.
4			16.68902	25.436	2.73948	6.268	13.462	22.
5					4.51749	8.754	38.076	44.
6					15.9453	20.295	107.694	88.
7					79.3296	59.154		

REMARKS. 1. There is a small variation in the inclination of planets' orbits, the longitude of nodes, the longitude of perihelion, and excentricity of orbits, the amount of which in 100 years is usually inserted in astronomical tables, and termed *secular variations*.

2. The diameter of the earth being 1. that of the sun will be 111.45 and that of the moon .2731. The density of the sun, (water being 1.) will be 1.1468, and that of moon, 3.339.

3 The inclination of the sun's axis is about 8°, and the time of his rotation about 25 days 6h.

4. The inclination of the moon's orbit to the ecliptic is about 5° 8′, that of her axis about 2°. 18′, and the time of her rotation = that of her revolution round the earth.

5. The periodical revolutions in the tables are those termed *sidereal*, and the distances of the satellites from their primaries are reckoned in semidiameters of their respective primaries.

6. The orbits of the 1st, 2d, and 3d, satellites of Jupiter are very nearly circular, and coincident with the orbit of Jupiter: but that of the 4th is very sensibly elliptical, and inclined to the orbit of Jupiter in an angle of about 1°. 448.

7. The elements of the above Tables are taken chiefly from Laplace and Lalande, the places being calculated for the beginning of the year 1750.

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CONTENTS.

ASTRONOMY EXPLAINED.

CHAP. I.

Of Astronomy in general.

1. OF all the sciences cultivated by mankind, *astronomy* is acknowledged to be, and undoubtedly is, the most sublime, the most interesting, and the most useful. For, by knowledge derived from this science, not only the magnitude of the earth is discovered, the situation and extent of the countries and kingdoms upon it ascertained, trade and commerce carried on to the remotest parts of the world, and the various products of several countries distributed for the health, comfort, and conveniency of its inhabitants; but our very faculties are enlarged with the grandeur of the ideas it conveys, our minds exalted above the low contracted prejudices of the vulgar, and our understandings clearly convinced, and affected with the conviction, of the existence, wisdom, power, goodness, immutability, and superintendency of the SUPREME BEING. So that, without an hyperbole, The general use of astronomy.

" *An undevout astronomer is mad.**"

2. From this branch of knowledge we also learn by what means or laws the Almighty carries on, and continues, the wonderful harmony, order, and connexion, observable throughout the planetary system; and are led, by very powerful arguments, to form this pleasing deduction—that minds capable

* Dr. Young's Night Thoughts.

of such deep researches, not only derive their origin from that adorable Being, but are also incited to aspire after a more perfect knowledge of his nature, and a stricter conformity to his will.

The Earth but a point as seen from the Sun.

3. By astronomy, we discover that the Earth is at so great a distance from the Sun, that if seen from thence it would appear no larger than a point; although its circumference is known to be 25,020 miles. Yet even this distance is so small, compared with that of the fixed stars, that if the orbit in which the Earth moves round the Sun were solid, and seen from the nearest star, it would likewise appear no larger than a point; although it is about 162 millions of miles in diameter. For the Earth, in going round the Sun, is 162 millions of miles nearer to some of the stars at one time of the year, than at another; and yet their apparent magnitudes, situations and distances from one another, still remain the same; and a telescope which magnifies above 200 times, does not sensibly magnify them. This proves them to be at least 400 thousand times farther from us than we are from the Sun.

4. It is not to be imagined that all the stars are placed in one concave surface, so as to be equally distant from us; but that they are placed at immense distances from one another, through unlimited space. So that there may be as great a distance between any two neighbouring stars, as between the Sun and those which are nearest to him. An observer, therefore, who is nearest any fixed star, will look upon it alone as a real Sun; and consider the rest as so many shining points, placed at equal distances from him in the firmament.

The stars are suns,

5. By the help of telescopes we discover thousands of stars which are invisible to the bare eye; and the better our glasses are, still the more stars become visible: so that we can set no limits either to their number or their distances. The celebrated HUYGENS carried his thoughts so far, as to believe it not impossible that there may be stars at such

and innumerable.

inconceivable distances, that their light has not yet reached the Earth since its creation; although the velocity of light be a million of times greater than the velocity of a cannon-ball, as shall be demonstrated afterward, § 197. 216.—And, as Mr. ADDISON very justly observes, this thought is far from being extravagant, when we consider that the universe is the work of infinite power, prompted by infinite goodness; having an infinite space to exert itself in; so that our imaginations can set no bounds to it.

6. The Sun appears very bright and large in comparison with the fixed stars, because we keep constantly near the Sun, in comparison with our immense distance from the stars. For, a spectator placed as near to any star as we are to the Sun, would see that star a body as large and bright as the Sun appears to us: and a spectator as far distant from the sun as we are from the stars, would see the Sun as small as we see a star, divested of all its circumvolving planets; and would reckon it one of the stars in numbering them. Why the Sun appears larger than the stars.

7. The stars, being at such immense distances from the Sun, cannot possibly receive from him so strong a light as they seem to have; nor any brightness sufficient to make them visible to us. For the Sun's rays must be so scattered and dissipated before they reach such remote objects, that they can never be transmitted back to our eyes, so as to render these objects visible by reflection. The stars therefore shine with their own native and unborrowed lustre, as the Sun does. And since each particular star, as well as the Sun, is confined to a particular portion of space, it is plain that the stars are of the same nature with the Sun. The stars are not enlightened by the Sun.

8. It is no ways probable that the Almighty, who always acts with infinite wisdom, and does nothing in vain, should create so many glorious suns, fit for so many important purposes, and place them at such distances from one another, without pro-

They are probably surrounded by planets.

per objects near enough to be benefited by their influence. Whoever imagines that they were created only to give a faint glimmering light to the inhabitants of this globe, must have a very superficial knowledge of astronomy, and a mean opinion of the Divine Wisdom: since, by an infinitely less exertion of creating power, the Deity could have given our Earth much more light by one single additional moon.

9. Instead then of one Sun and one world only in the universe, as the unskilful in astronomy imagine, *that* science discovers to us such an inconceivable number of suns, systems, and worlds, dispersed through boundless space, that if our Sun, with all the planets, moons, and comets, belonging to it, were annihilated, they would be no more missed, by an eye that could take in the whole creation, than a grain of sand from the sea-shore—the space they possess being comparatively so small, that it would scarce be a sensible blank in the universe. Saturn, indeed, the outermost of our planets, revolves about the Sun in an orbit of 4884 millions of miles in circumference;* and some of our comets make excursions upwards of ten thousand millions of miles beyond Saturn's orbit; and yet, at that amazing distance, they are incomparably nearer to the Sun than to any of the stars. This is evident from their keeping clear of the attractive power of all the stars, and returning periodically by virtue of the Sun's attraction.

The stellar planets may be habitable,

10. From what we know of our own system, it may be reasonably concluded that all the rest are with equal wisdom contrived, situate, and provided with accommodations for rational inhabitants. Let us therefore take a survey of the system to which we belong, the only one accessible to us, and from thence we shall be the better

* The Georgian planet, discovered since Mr. Ferguson's time, revolves round the Sun in an orbit 5673 millions of miles in circumference.

enabled to judge of the nature and end of the other systems of the universe. For, although there is an almost infinite variety in the parts of the creation, which we have opportunities of examining, yet there is a general analogy running through and connecting all the parts into one scheme, one design, one whole.

11. And then, to an attentive considerer, it will appear highly probable, that the planets of our system, together with their attendants called satellites or moons, are much of the same nature with our Earth, and destined for the like purposes. They are all solid opaque globes, capable of supporting animals and vegetables. Some of them are larger, some less, and some nearly of the same size of our Earth. They all circulate round the Sun, as the Earth does, in shorter or longer times, according to their respective distances from him; and have, where it would not be inconvenient, regular returns of summer and winter, spring and autumn. They have warmer and colder climates, as the various productions of our Earth require: and in such as afford a possibility of discovering it, we observe a regular motion round their axes like that of our Earth, causing an alternate return of day and night; which is necessary for labour, rest, and vegetation; and that all parts of their surfaces may be alternately exposed to the rays of the Sun.

as our solar planets are.

12. Such of the planets as are farthest from the Sun, and therefore enjoy least of his light, have that deficiency made up by several moons, which constantly accompany, and revolve about them; as our Moon revolves about the Earth. The remotest planet* has, over and above, a broad ring encompassing it; which, like a lucid zone in the heavens, reflects the Sun's light very copiously on that planet: so that if the remoter planets have the Sun's light fainter by day than our earth, they have an addition made to it morning and evening by one or more of

The farthest from the Sun have most moons to enlighten their nights.

* Saturn is now known to have two of these lucid zones or rings.

Our Moon mountainous like the Earth.

their moons, and a greater quantity of light in the night-time.

13. On the surface of the Moon, because it is nearer to us than any other of the celestial bodies are, we discover a nearer resemblance of our Earth. For, by the assistance of telescopes, we observe the Moon to be full of high mountains, large vallies, and deep cavities. These similarities leave us no room to doubt, that all the planets and moons in the system, are designed as commodious habitations for creatures endowed with capacities of knowing and adoring their beneficent Creator.

14. Since the fixed stars are prodigious spheres of fire like our Sun,* and at inconceivable distances from one another, as well as from us, it is reasonable to conclude, they are made for the same purposes that the Sun is; each to bestow light, heat, and vegetation on a certain number of inhabited planets; kept by gravitation within the sphere of its activity.

Numberless suns and worlds.

15. What an august, whan an amazing conception, if human imagination can conceive it, does this give of the works of the Creator! Thousands of thousands of suns, multiplied without end, and ranged all around us, at immense distances from each other; attended by ten thousand times ten thousand worlds, all in rapid motion, yet calm, regular, and harmonious, invariably keeping the paths prescribed them; and these worlds peopled with myriads of intelligent beings, formed for endless progression in perfection and felicity!

16. If so much power, wisdom, goodness, and magnificence be displayed in the material creation, which is the least considerable part of the universe, how great, how wise, how good, must HE BE, who made and governs the whole!

* Though the Sun may not, strictly speaking, be a great sphere of fire, yet it is undoubtedly the principal source of light and heat to the other bodies in the system.

CHAP. II.

A brief Description of the SOLAR SYSTEM.

17. THE Sun, with the planets and comets which move round him as their centre, constitute the *solar system*. Those planets which are near the Sun not only finish their circuits sooner, but likewise move faster in their respective orbits, than those which are more remote from him. Their motions are all performed from west to east, in orbits nearly circular. Their names, distances, magnitudes, and periodical revolutions, are as follows: *Plate* I Fig. 1. The Solar System.

18. The Sun ☉, an immense globe of fire, is placed near the common centre, or rather in the lower* focus of the orbits of all the planets and comets†; and turns round his axis in 25 days 6 hours, as is evident by the motion of spots seen on his surface. His diameter is computed to be 763,000 miles; and by the various attractions of the circumvolving planets, he is agitated by a small motion The Sun. Fig. 1.

* If the two ends of a thread be tied together, and the thread be then thrown loosely round two pins stuck in a table, and moderately stretched by the point of a black-lead pencil carried round by an even motion, and light pressure of the hand, and oval or ellipsis will be described; and the points where the pins are fixed are called the *foci* or focuses of the ellipsis. The orbits of all the planets are elliptical, and the Sun is placed in or near one of the *foci* of each of them: and *that* in which he is placed, is called the *lower focus*.

† Astronomers are not far from the truth when they reckon the Sun's centre to be in the lower focus of all the planetary orbits. Though, strictly speaking, if we consider the focus of Mercury's orbit to be in the Sun's centre, the focus of Venus's orbit will be in the common centre of gravity of the Sun and Mercury; the focus of the Earth's orbit in the common centre of gravity of the Sun, Mercury, and Venus, the focus of the orbit of Mars in the common centre of gravity of the Sun, Mercury, Venus, and the Earth, and so of the rest. Yet the focuses of the orbits of all the planets, except Saturn, will not be sensibly removed from the centre of the Sun, nor will the focus of Saturn's orbit recede sensibly from the common centre of gravity of the Sun and Jupiter.

Plate I. round the centre of gravity of the system. All the planets, as seen from him, move the same way, and according to the order of the signs in the graduated circle ♈ ♉ ♊ ♋, &c. which represents the great ecliptic in the heavens: but, as seen from any one planet, the rest appear sometimes to go backward, sometimes forward, and sometimes to stand still. These apparent motions are not in circles nor in ellipses, but* in looped curves, which never return into themselves. The comets come from all parts of the heavens, and move in all directions.

The axes of the planets, what.

19. Having mentioned the Sun's turning round his axis, and as there will be frequent occasion to speak of the like motion of the Earth and other planets, it is proper here to inform the young *Tyro* in astronomy, that neither the Sun nor planets have material axes to turn upon, and support them, as in the little imperfect machines contrived to represent them. For the axis of a planet is an imginary line, conceived to be drawn through its centre, about which it revolves as if on a real axis. The extremities of this axis, terminating in opposite points of the planet's surface, are called its *poles.* That which points toward the *northern* part of the heavens, is called the *north pole;* and the other, pointing toward the *southern* part, is called the *south pole.* A bowl whirled from one's hand into the open air, turns round such a line within itself, while it moves forward; and such are the lines we mean, when we speak of the axes of the heavenly bodies.

Their orbits are not in the same plane with the ecliptic.

20. Let us suppose the Earth's orbit to be a thin, even, solid plane; cutting the Sun through the centre, and extended out as far as the starry heavens, where it will mark the great circle called the *ecliptic.* This circle we suppose to be divided into 12 equal parts, called *signs;* each sign into 30 equal parts, called *degrees;* each degree into 60 equal parts, called *minutes;* and each minute into 60

* As represented in Plate III. Fig. I. and described § 138.

into 60 equal parts, called *seconds:* so that a second is the 60th part of a minute; a minute the 60th part of a degree; and a degree the 360th part of a circle, or 30th part of a sign. The planes of the orbits of all the other planets likewise cut the Sun in halves; but, extended to the heavens, form circles different from one another, and from the ecliptic; one half of each being on the north side, and the other on the south side of it. Consequently the orbit of each planet crosses the ecliptic in two opposite points, which are called the planets' *nodes.* These nodes are all in different parts of the ecliptic; and therefore, if the planetary tracks remained visible in the heavens, they would in some measure resemble the different ruts of waggon wheels, crossing one another in different parts, but never going far asunder. That node, or intersection of the orbit of any planet with the Earth's orbit, from which the planet ascends northward above the ecliptic, is called the *ascending node* of the planet: and the other, which is directly opposite thereto, is called its *descending node.* Saturn's ascending node* is in 21 deg. 32 min. of Cancer ♋; Jupiter's in 8 deg. 49 min. of the same sign; Mars's in 18 deg. 22 min. of Taurus ♉; Venus's in 14 deg. 44 min. of Gemini ♊; and Mercury's in 16 deg. 2 min. of Taurus. Here we consider the Earth's orbit as the standard, and the orbits of all the other planets as oblique to it.

Plate I.

Their nodes.

Where situate.

21. When we speak of the planets' orbits, all that is meant is, their paths through the open and unresisting space in which they move, and are retained by the attractive power of the Sun, and the projectile force impressed upon them at first. Between this power and force there is so exact an adjustment, that they continue in the same tracks without any solid orbits to confine them.

The planets' orbits, what.

* In the year 1790.

Plate I. Mercury Fig. I.

22. MERCURY, the nearest planet to the Sun, goes round him, in the circle marked ☿, in 87 days, 23 hours of our time, nearly; which is the length of his year. But being seldom seen, and no spots appearing on his surface or disc, the time of his rotation on his axis, or the length of his days and nights is as yet unknown. His distance from the Sun is computed to be 32 millions of miles, and his diameter 2600. In his course round the Sun, he moves at the rate of 95 thousand miles every hour. His light and heat from the Sun are almost seven times as great as ours; and the Sun appears to him almost seven times as large as to us. The great heat on this planet is no argument against its being inhabited; since the Almighty could as easily suit the bodies and constitutions of its inhabitants to the heat of their dwelling, as he has done ours to the temperature of our Earth. And it is very probable that the people there have just such an opinion of us, as we have of the inhabitants of Jupiter and Saturn; namely, that we must be intolerably cold, and have very little light, at so great a distance from the Sun.

May be inhabited.

Has like phases with the Moon.

23. This planet appears to us with all the various phases of the Moon, when viewed at different times by a good telescope: save only, that he never appears quite full, because his enlightened side is never turned directly toward us, but when he is so near the Sun as to be lost to our sight in its beams. And, as his enlightened side is always toward the Sun, it is plain that he shines not by any light of his own; for if he did, he would constantly appear round. That he moves about the Sun in an orbit within the Earth's orbit, is also plain (as will be more largely shewn by and by, § 141, *& seq.)* because he is never seen opposite to the Sun, nor indeed above 56 times the Sun's breadth from his centre.

24. His orbit is inclined seven degrees to the ecliptic. *That* node, § 20, from which he ascends northward above the ecliptic, is in the 16th degree of Taurus; and the opposite node, in the 16th degree of Scorpio. The Earth is in these points on the 7th of *November* and 5th of *May*; and when Mercury comes to either of his nodes at his* inferior conjunction about these times, he will appear to pass over the disc or face of the Sun, like a dark round spot. But in all other parts of his orbit his conjunctions are invisible; because he either passes above or below the Sun.

Plate I. His orbit and nodes.

25. Mr. Whiston has given us an account of several periods at which Mercury might be seen on the Sun's disc, *viz*. In the year 1782, *Nov*. 12th, at 3 h. 44 m. in the afternoon, 1786, *May* 4th, at 6 h. 57 m. in the forenoon; 1789, *Nov*. 5th, at 3 h. 55 m. in the afternoon; and 1799, *May* 7th, at 2 h. 34 m. in the afternoon. There were several intermediate transits, but none of them visible at *London*.

When seen as if upon the Sun.

26. Venus, the next planet in order, is computed to be 59 millions of miles from the Sun; and by moving at the rate of 69 thousand miles every hour, in her orbit in the circle marked ♀, she goes round the Sun in 224 days, 17 hours of our time, nearly; in which, though it be the full length of her year, she has only 9¼ days, according to Bianchini's observations†; so that, to her,

Venus. Fig. I.

* When he is between the Earth and the Sun in the nearest part of his orbit.

† The elder Cassini had concluded from observations made by himself in 1667, that Venus revolved on her axis in a little more than 23 h. because in 24 h. he found that a spot on her surface was about 15° more advanced than it was at the day before; and it appeared to him that the spot was very sensibly advanced in a quarter of an hour. In 1728, Bianchini published a splendid work, in folio, at Rome, entitled *Hesperi et Phosphori nova phænomena*; in which are the observations here referred to. Bianchini agrees

Plate I. every day and night together is as long as $24\frac{1}{3}$ days and nights with us. This odd quarter of a day in every year makes every fourth a leap-year to Venus; as the like does to our Earth. Her diameter is 7906 miles; and by her diurnal motion the inhabitants about her equator are carried 43 miles every hour, beside the 69,000 above-mentioned.

Her orbit lies between the Earth and Mercury.

27. Her orbit includes that of Mercury within it; for at her greatest elongation, or apparent distance from the Sun, she is 96 times the breadth of that luminary from his centre; which is almost double of Mercury's greatest elongation. Her orbit is included by the Earth's; for if it were not, she might be seen as often in opposition to the Sun, as she is in conjunction with him; but she has never been seen 90 degrees, or a fourth part of a circle from the Sun.

She is our morning and evening star by turns.

28. When Venus appears west of the Sun, she rises before him in the morning, and is called the *morning star:* when she appears east of the Sun, she shines in the evening after he sets, and is then called the *evening star:* being each in its turn for 290 days. It may perhaps be surprising at first view, that Venus should keep longer on the east or west of the Sun, than the whole time of her period round him. But the difficulty vanishes when we consider that the Earth is all the while going round the Sun the same way, though not so quick as Venus: and therefore her relative motion to the

perfectly with Cassini that the spots, which are seen on the surface of Venus, advance about 15° in 24 h. but he asserts that he could not perceive they had made any advance in 3 h. and therefore concludes that instead of making one complete revolution and 15° of another, as Cassini conjectured, in 24 h. these spots advance but the odd 15° in that time, and that the time of a revolution is somewhat more than 24 days. The arguments in favour of the two hypotheses are very equal, but almost every astronomer, except Mr. Ferguson, has adopted Cassini's.

Earth must in every period be as much slower than her absolute motion in her orbit, as the Earth during that time advances forward in the ecliptic; which is 220 degrees. To us she appears, through a telescope, in all the various shapes of the moon.

29. The axis of Venus is inclined 75 degrees to the axis of her orbit; which is 51½ degrees more than our Earth's axis is inclined to the axis of the ecliptic: and therefore her seasons vary much more than ours do. The north pole of her axis inclines toward the 20th degree of Aquarius; our Earth's to the beginning of Cancer; consequently the northern parts of Venus have summer in the signs where those of our Earth have winter, and *vice* [redacted]

Remarkable appearances.

30. The* artificial day at each pole of Venus is as long as 112½† natural days on our Earth.

Her tropics and polar circles how situate.

31. The Sun's greatest declination on each side of her equator amounts to 75 degrees; therefore her‡ tropics are only 15 degrees from her poles; and her‖ polar circles are as far from her equator. Consequently the tropics of Venus are between her polar circles and her poles; contrary to what those of our Earth are.

The Sun's daily course.

32. As her annual revolution contains only 9¼ of her days, the Sun will always appear to go through a whole sign, or twelfth part of her orbit, in a little more than three quarters of her

* The time between the Sun's rising and setting.

† One entire revolution, or 24 hours.

‡ These are lesser circles parallel to the equator, and as many degrees from it, toward the poles, as the axis of the planet is inclined to the axis of its orbit. When the Sun is advanced so far north or south of the equator, as to be directly over either tropic, he goes no farther, but returns toward the other.

‖ These are lesser circles round the poles, and as far from them as the tropics are from the equator. The poles are the very north and south points of the planet.

natural day, or nearly in 18¾ of our days and nights.

and great declination. 33. Because her day is so great a part of her year, the Sun changes his declination in one day so much, that if he passes vertically, or directly over head of any given place on the tropic, the next day he will be 26 degrees from it; and whatever place he passes vertically over when in the Equator, one day's revolution will remove him 36½ degrees from it. So that the Sun changes his declination every day in Venus about 14 degrees more, at a mean rate, than he does in a quarter of a year on our Earth. This appears to be providentially ordered, for preventing the too great effects of the Sun's heat, (which is twice as great on Venus as on the Earth,) so that he cannot shine perpendicularly on the same places for two days together; and on that account, the heated places have time to cool.

To determine the points of the compass at her poles. 34. If the inhabitants about the north pole of Venus fix their south, or meridian line, through that part of the heavens where the Sun comes to his greatest height, or north declination, and call those the east and west points of their horizon, which are 90 degrees on each side from that point where the horizon is cut by the meridian line, these inhabitants will have the following remarkable appearances—

The Sun will rise 22½ degrees north of the east, and going on 11.½ degrees, as measured on the plane of the* horizon, he will cross the meridian at an altitude of 1½ degrees; then making an entire revolution without setting, he will cross it again at an altitude of 48½ degrees. At the next revolution he will cross the meridian as he comes to his greatest height and declination, at the

* The limit of any inhabitant's view, where the sky seems to touch the planet all round him.

altitude of 75 degrees; being then only 15 degrees from the zenith, or that point of the heavens which is directly over head: and thence he will descend in the like spiral manner, crossing the meridian first at the altitude of 42½ degrees, next at the altitude of 12½ degrees; and going on thence 11½ degrees, he will set 2¾ degrees north of the west. So that, after having made 1¾ revolutions above the horizon, he descends below it to exhibit the like appearances at the south pole.

35. At each pole, the Sun continues half a year without setting in summer, and as long without rising in winter; consequently the polar inhabitants of Venus have only one day and one night in the year; as it is at the poles of our earth. But the difference between the heat of summer and cold of winter, or of mid-day and mid-night, on Venus, is much greater than on the Earth: because on Venus, as the Sun is for half a year together above the horizon of each pole in its turn, so he is for a considerable part of that time near the zenith; and during the other half of the year always below the horizon, and for a great part of that time at least 70 degrees from it. Whereas, at the poles of our Earth, although the Sun is for half a year together above the horizon; yet he never ascends above, nor descends below it, more than 23½ degrees. When the Sun is in the equinoctial, he is seen with one half of his disc above the horizon of the north pole, and the other half above the horizon of the south pole; so that his centre is in the horizon of both poles: and then descending below the horizon of one, he ascends gradually above that of the other. Hence, in a year, each pole has one spring, one autumn, a summer as long as them both, and a winter equal in length to the other three seasons.

Surprising appearances at her poles.

36. At the polar circles of Venus, the seasons

At her polar circles.

are much the same as at the equator, because there are only 15 degrees between them, § 31; only the winters are not quite so long, nor the summers so short: but the four seasons come twice round every year.

At her tropics. 27. At Venus's tropics, the Sun continues for about fifteen of our weeks together without setting in summer; and as long without rising in winter. While he is more than 15 degree from the equator, he neither rises to the inhabitants of the one tropic, nor sets to those of the other; whereas, at our terrestrial tropics, he rises and sets every day of the year.

38. At Venus's tropics, the seasons are much the same as at her poles, only the summers are a little longer, and the winters a little shorter.

At her equator. 39. At her equator, the days and nights are always of the same length; and yet the diurnal and nocturnal arches are very different, especially when the Sun's declination is about the greatest: for then, his meridian altitude may sometimes be twice as great as his midnight depression, and at other times the reverse. When the Sun is at his greatest declination, either north or south, his rays are as oblique at Venus's equator, as they are at London on the shortest day of winter. Therefore, at her equator there are two winters, two summers, two springs, and two autumns every year. But because the Sun stays for some time near the tropics, and passes so quickly over the equator, every winter there will be almost twice as long as summer: the four seasons returning twice in that time, which consist only of 9¼ days.

40. Those parts of Venus which lie between the poles and tropics, between the tropics and polar circles, and also between the polar circles and equator, partake more or less of the phenomena of those circles, as they are more or less distant from them.

41. From the quick change of the Sun's declination it happens, that if he rises due east on any day, he will not set due west on that day, as with us. For if the place where he rises due east be on the equator, he will set on that day almost west-north-west, or about 18½ degrees north of the west. But if the place be in 45 degrees north latitude, then on the day that the Sun rises due east he will set north-west-by-west, or 33 degrees north of the west. And in 62 degrees north latitude, when he rises in the east, he sets not in that revolution, but just touches the horizon 10 degrees to the west of the north point; and ascends again, continuing for 3¼ revolutions above the horizon without setting. Therefore no place has the forenoon and afternoon of the same day equally long, unless it be on the equator, or at the poles.

Great difference of the Sun's amplitude at rising and setting.

42. The Sun's altitude at noon, or any other time of the day, and his amplitude at rising and setting, being very different at places on the same parallel of latitude, according to the different longitudes of those places, the longitude will be almost as easily found on Venus, as the latitude is found on the Earth. This is an advantage we can never have, because the daily change of the Sun's declination, is by much too small for that important purpose.

The longitude of places easily found in Venus.

43. On this planet, where the Sun crosses the equator in any year, he will have 9 degrees of declination from that place on the same day and hour next year, and will cross the equator 90 degrees farther to the west; which makes the time of the equinox a quarter of a day (or about six of our days) later every year. Hence, although the spiral in which the Sun's motion is performed be of the same sort every year, yet it will not be the very same; because the Sun will not pass vertically over the same places till four annual revolutions are finished.

Her equinoxes shift a quarter of a day forward every year.

Every fourth year a leap year to to Venus.

44. We may suppose that the inhabitants of Venus will be careful to add a day to some particular part of every fourth year; which will keep the same seasons to the same days. For, as the great annual change of the equinoxes and solstices shifts the seasons a quarter of a day every year, they would be shifted through all the days of the year in 36 years. But by means of this intercalary day, every fourth year will be a leap-year; which will bring her time to an even reckoning, and keep her calendar always right.

When she will appear on the Sun.

45. Venus's orbit is inclined 3 degrees 24 minutes to the Earth's; and crosses it in the 15th degrees of Gemini and of Sagittarius; and therefore, when the Earth is about these points of the ecliptic at the time that Venus is in her inferior conjunction, she will appear like a spot on the Sun, and afford a more certain method of finding the distances of all the planets from the Sun, than any other yet known. But these appearances happening very seldom, will be only twice visible at *London* for one hundred and ten years to come. The first time will be in 1761, *June* the 6th, in the morning; and the second in 1769, on the 3d of *June*, in the evening. Excepting such transits as these, she exhibits the same appearances to us regularly every eight years; her conjunctions, elongations, and times of rising and setting, being very nearly the same, on the same days as before.

She may have a moon, although we cannot see it.

46. Venus may have a satellite or moon, although it be undiscovered by us. This will not appear very surprising, if we consider how inconveniently we are placed for seeing it. For its enlightened side can never be fully turned toward us, except when Venus is beyond the Sun; and then, as Venus appears but little larger than an ordinary star, her moon may be too small to be perceived at such a distance. When she is between us and the Sun, her full moon has its dark side toward us; and then we cannot see it any more than we can our own moon at the time of change. When

Venus is at her greatest elongation, we have but one half of the enlightened side of her full moon toward us; and even then it may be too far distant to be seen by us. But if she have a moon, it may certainly be seen with her upon the Sun, in the year 1761; unless its orbit be considerably inclined to the ecliptic: for if it should be in conjunction or opposition at that time, we can hardly imagine that it moves so slow as to be hid by Venus all the six hours that she will appear on the Sun's disc*. Plate I.

47. The EARTH is the next planet above Venus in the system. It is 82 millions of miles from the Sun, and goes round him, in the circle ⊕, in 365 days 5 hours 49 minutes, from any equinox or solstice to the same again; but from any fixed star to the same again, as seen from the Sun, in 365 days 6 hours and 9 minutes: the former being the length of the tropical year, and the latter the length of the sidereal. It travels at the rate of 58 thousand miles every hour; which motion, though 120 times swifter than that of a cannon-ball, is little more than half as swift as Mercury's motion in his orbit. The Earth's diameter is 7970 miles; and by turning round its axis every 24 hours, from west to east, it causes an apparent diurnal motion of all the heavenly bodies, from east to west. By this rapid motion of the Earth on its axis, the inhabitants about the equator are carried 1042 miles every hour, while those on the parallel of *London* are carried only about 580; besides the 58 thousand miles, by the annual motion above-mentioned, which is common to all places whatever.

The Earth. Fig. I.

Its diurnal and annual motion.

48. The Earth's axis makes an angle of $23\frac{1}{2}$ degrees with the axis of its orbit; and keeps always the same oblique direction; inclining toward the

Inclination of its axis.

* Both her transits are over since this was written, and no satellite was seen with Venus on the Sun's disc.

same fixed star* throughout its annual course, which causes the returns of spring, summer, autumn, and winter; as will be explained at large in the tenth chapter.

A proof of its being round.

49. The Earth is round like a globe; as appears, 1. By its shadow in eclipses of the Moon; which shadow is always bounded by a circular line; § 314. 2. By our seeing the masts of a ship while the hull is hid by the convexity of the water. 3. By its having been sailed round by many navigators. The hills take off no more from the roundness of the Earth in comparison, than grains of dust do from the roundness of a common globe.

Its number of square miles.

50. The seas and unknown parts of the Earth (by a measurement of the best maps) contain 160 millions 522 thousand and 26 square miles; the inhabited parts 38 millions 990 thousand 569: *Europe* 4 millions 456 thousand and 65; *Asia* 10 millions 768 thousand 823; *Africa* 9 millions 654 thousand 807; *America* 14 millions 110 thousand 874. In all, 199 millions 512 thousand 595; which is the number of square miles on the whole surface of our globe.

The proportion of land and sea.

51. Dr. LONG, in the first volume of his Astronomy, p. 168, mentions an ingenious and easy method of finding nearly what proportion the land bears to the sea; which is, to take the papers of a large terrestrial globe, and after separating the land from the sea, with a pair of scissars, to weigh them carefully in scales. This supposes the globe to be exactly delineated, and the papers all of equal thickness. The doctor made the experiment on the papers of Mr. SENEX's seventeen inch globe; and found that the sea-papers weighed 349 grains, and the land only 124: by which it appears that almost

* This is not strictly true, as will appear when we come to treat of the recession of the equinoctial points in the heavens, § 246; which recession is equal to the deviation of the Earth's axis from its parallelism, but this is rather too small to be sensible in an age, except to those who make very nice observations.

three fourth parts of the surface our Earth between the polar circles are covered with water, and that little more than one fourth is dry land. The doctor omitted weighing all within the polar circles; because there is no certain measurement of the land within them, so as to know what proportion it bears to the sea.

52. The Moon is not a planet, but only a satellite or attendant of the Earth; going round the Earth from change to change in 29 days 12 hours and 44 minutes; and round the Sun with it every year. The Moon's diameter is 2180 miles; and her distance from the Earth's centre 240 thousand. She goes round her orbit in 27 days 7 hours 43 minutes, moving about 2290 miles every hour; and turns round her axis exactly in the time that she goes round the Earth, which is the reason of her keeping always the same side toward us, and that her day and night, taken together, is as long as our lunar month. The Moon

53. The Moon is an opaque globe, like the Earth, and shines only by reflecting the light of the Sun: therefore, while that half of her which is toward the Sun is enlightened, the other half must be dark and invisible. Hence, she disappears when she comes between us and the Sun; because her dark side is then toward us. When she is gone a little way forward, we see a little of her enlightened side; which still increases to our view, as she advances forward, until she comes to be opposite to the Sun; and then her whole enlightened side is toward the Earth, and she appears with a round illumined orb, which we call the *full moon:* her dark side being then turned away from the Earth. From the full she seems to decrease gradually as she goes through the other half of her course; shewing us less and less of her enlightened side every day, till her next change or conjunction with the Sun, and then she disappears as before. Her phase

A proof that she shines not by her own light. 54. This continual change of the Moon's phases demonstrates that she shines not by any light of her own; for if she did, being globular, we should always see her with a round full orb like the Sun. Her orbit is represented in the scheme by the little circle *m*, upon the Earth's orbit ⊕. It is indeed drawn fifty times too large in proportion to the Earth's; and yet is almost to small too be seen in the diagram.

Fig. I.

One half of her always enlightened. 55. The Moon has scarce any difference of seasons; her axis being almost perpendicular to the ecliptic. What is very singular, one half of her has no darkness at all; the Earth constantly affording it a strong light in the Sun's absence; while the other half has a fortnight's darkness, and a fortnight's light by turns.

Our Earth is her moon. 56. Our Earth is a moon to the Moon; waxing and waneing regularly, but appearing thirteen times as big, and affording her thirteen times as much light, as she does to us. When she changes to us, the Earth appears full to her, and when she is in her first quarter to us, the Earth is in its third quarter to her; and *vice versa*.

57. But from one half of the Moon, the Earth is never seen at all. From the middle of the other half, it is always seen over head; turning round almost thirty times as quick as the Moon does. From the circle which limits our view of the Moon, only one half of the Earth's side next her is seen; the other half being hid below the horizon of all places on that circle. To her, the Earth seems to be the largest body in the universe: appearing thirteen times as large as she does to us.

58. The Moon has no atmosphere of any visible density surrounding her, as we have: for if she had, we could never see her edge so well defined as it appears; but there would be a sort of mist or haziness around her, which would make the stars look fainter, when they are seen through it. But observation proves, that the stars which disap-

A proof of the Moon's having no atmosphere.

pear behind the Moon, retain their full lustre until they seem to touch her very edge, and then they vanish in a moment. This has been often observed by astronomers, but particularly by CASSINI of the star φ in the breast of Virgo, which appears single and round to the bare eye; but through a refracting telescope of 16 feet, appears to be two stars so near together, that the distance between them seems to be but equal to one of their apparent diameters. The moon was observed to pass over them on the 21st of *April* 1720, *N. S.* and as her dark edge drew near to them, it caused no change whatever in their colour or situation. At 25 min. 14 sec. past 12 at night, the most westerly of these stars was hid by the dark edge of the Moon; and in 30 seconds afterward, the most easterly star was hid: each of them disappearing behind the Moon in an instant, without any preceding diminution of magnitude or brightness; which by no means could have been the case if there were an atmosphere round the Moon: for then one of the stars falling obliquely into it before the other, ought, by refraction, to have suffered some change in its colour, or in its distance from the other star, which was not yet entered into the atmosphere. But no such alteration could be perceived; though the observation was made with the utmost attention to that particular; and was very proper to have made such a discovery. The faint light which has been seen all round the Moon, in total eclipses of the Sun, has been observed, during the time of darkness, to have its centre coincident with the centre of the Sun; and was therefore much more likely to arise from the atmosphere of the Sun, than from that of the Moon; for if it had been owing to the latter, its centre would have gone along with the Moon's.*

* It has been lately ascertained by Mr. Schroeter, that the Moon is indeed furnished with an atmosphere, similar to that of the Earth, and of proportional density: the former being about one 29th part the density of the latter.

Nor seas. 59. If there were seas in the Moon, she could have no clouds, rains, or storms, as we have; because she has no such atmosphere to support the vapours which occasion them. And every one knows, that when the Moon is above our horizon in the night time, she is visible, unless the clouds of our atmosphere hide her from our view; and all parts of her appear constantly with the same clear, serene, and calm aspect. But those dark parts of the Moon, which were formerly thought to be seas, are now found to be only vast deep cavities, and places which reflect not the Sun's light so strongly as others; having many caverns and pits, whose shadows fall within them, and are always dark on the side next the Sun. This demonstrates their being hollow: and most of these pits have little knobs like hillocks standing within them, and casting shadows also; which cause these places to appear darker than others which have fewer, or less remarkable caverns. All these appearances shew that there are no seas in the Moon; for if there were any, their surfaces would appear smooth and even like those on the Earth.

She is full of caverns and deep pits.

The stars always visible to the Moon. 60. There being no atmosphere about the Moon, the heavens in the day time have the appearance of night to a Lunarian who turns his back toward the Sun; the stars then appearing as bright to him as they do in the night to us. For it is entirely owing to our atmosphere that the heavens are bright about us in the day.

61. As the Earth turns round its axis, the several continents, seas, and islands, appear to the Moon's inhabitants like so many spots of different forms and brightness, moving over its surface; but much fainter at some times than others, as our clouds cover them or leave them. By these spots the Lunarians can determine the time of the Earth's diurnal motion, just as we do the motion of the Sun; and perhaps they measure their time by the motion of the Earth's spots; for they cannot have a truer dial.

The Earth a dial to the Moon.

62. The Moon's axis is so nearly perpendicular to the ecliptic, that the Sun never removes sensibly from her equator: and the * obliquity of her orbit, which is next to nothing as seen from the Sun, cannot cause the Sun to decline sensibly from her equator. Yet her inhabitants are not destitute of means for ascertaining the length of their year, though their method and ours must differ. We can know the length of our year by the return of our equinoxes; but the Lunarians, having always equal day and night, must have recourse to another method; and we may suppose, they measure their year by observing when either of the poles of our Earth begins to be enlightened, and the other to disappear, which is always at our equinoxes; they being conveniently situate for observing great tracts of land about our Earth's poles, which are entirely unknown to us. Hence we may conclude, that the year is of the same absolute length both to the Earth and Moon, though very different as to the number of days: we having $365\frac{1}{4}$ natural days, and the Lunarians only $12\frac{7}{19}$; every day and night in the Moon being as long as $29\frac{1}{2}$ on the Earth.

Plate I.

How the Lunarians may know the length of their year,

63. The Moon's inhabitants, on the side next the Earth, may as easily find the longitude of their places as we can find the latitude of ours. For the Earth keeping constantly, or very nearly so, over one meridian of the Moon, the east or west distances of places from that meridian are as easily found, as we can find our distance from the equator by the altitude of our celestial poles.

and the longitudes of their places.

64. The planet MARS is next in order, being the first above the Earth's orbit. His distance from the Sun is computed to be 125 millions of miles; and

Mars.

* The Moon's orbit crosses the ecliptic in two opposite points, called the moon's nodes: so that one half of her orbit is above the ecliptic, and the other half below it. The angle of its obliquity is 5 1-3 degrees.

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by travelling at the rate of 47 thousand miles every hour, in the circle ♂, he goes round the Sun in 686 of our days and 23 hours, which is the length of his year, and contains 667¾ of his days; every day and night together being 40 minutes longer than with us. His diameter is 4444 miles; and by his diurnal rotation, the inhabitants about his equator are carried 556 miles every hour. His quantity of light and heat is equal but to one half of ours; and the Sun appears but half as large to his inhabitants as to us.

Fig. I.

His atmosphere and phases.

65. This planet being but a fifth part of the magnitude of the Earth, if any moon attends him, it must be very small, and has not yet been discovered by our best telescopes. He is of a fiery red colour, and by his appulses to some of the fixed stars, seems to be encompassed by a very gross atmosphere. He appears sometimes gibbous, but never horned: which shews both that his orbit includes the Earth's within it, and that he shines not by his own light.

66. To Mars, our Earth and Moon appear like two moons, a larger and a less: changing places with one another, and appearing sometimes horned, sometimes half or three quarters illuminated, but never full; nor at most above one quarter of a degree from each other; although they are 240 thousand miles asunder.

How the other planets appear to Mars.

67. Our Earth appears almost as large to Mars as Venus does to us; and at Mars it is never seen above 48 degrees from the Sun. Sometimes it appears to pass over the disc of the Sun, and so do Mercury and Venus. But Mercury can never be seen from Mars by such eyes as ours, unassisted by proper instruments, and Venus will be as seldom seen as we see Mercury. Jupiter and Saturn are as visible to the inhabitants of Mars as to us. His axis is perpendicular to the ecliptic, and his orbit is inclined to it in an angle of 1 degree 50 minutes.

Jupiter.

68. JUPITER, the largest of all the planets, is still higher in the system, being about 426 millions

of miles from the Sun: and going at the rate of 25 thousand miles every hour, in his orbit, which is represented by the circle ♃. He finishes his annual period in eleven of our years 314 days and 12 hours. He is above 1000 times as large as the Earth; his diameter being 81,000 miles; which is more than ten times the diameter of the Earth. *Plate I. Fig. I.*

69. Jupiter turns round his axis in 9 hours 56 minutes; so that his year contains 10 thousand 470 days; the diurnal velocity of his equatorial parts being greater than that with which he moves in his annual orbit—a singular circumstance, as far as we know. By this prodigious quick rotation, his equatorial inhabitants are carried 25 thousand 920 miles every hour (which is 920 miles an hour more than an inhabitant of our Earth's equator moves in 24 hours) beside the 25 thousand above mentioned, which is common to all parts of his surface, by his annual motion. **The number of days in his year.**

70. Jupiter is surrounded by faint substances, called *belts*; in which so many changes appear, that they are generally thought to be clouds; for some of them have been first interrupted and broken, and then have vanished entirely. They have sometimes been observed of different breadths, and afterward have all become nearly of the same breadth. Large spots have been seen in these belts; and when a belt vanishes, the contiguous spots disappear with it. The broken ends of some belts have been generally observed to revolve in the same time with the spots: only those nearer the equator in somewhat less time than those near the poles; perhaps on account of the Sun's greater heat near the equator, which is parallel to the belts and course of the spots. Several large spots, which appear round at one time, grow oblong by degrees, and then divide into two or three round spots. The periodical time of the spots near the equator is 9 hours 50 minutes, but of these near the poles 9 hours 56 minutes. See Dr. SMITH's *Optics*, § 1004, &c *seq.* **His belts and spots.**

He has no change of seasons, 71. The axis of Jupiter is so nearly perpendicular to his orbit, that he has no sensible change of seasons; which is a great advantage, and wisely ordered by the Author of Nature. For, if the axis of this planet were inclined any considerable number of degrees, just so many degrees round each pole would in their turn be almost six of our years together in darkness. And, as each degree of a great circle on Jupiter contains 706 of our miles, at a mean rate, it is easy to judge what vast tracts of land would be rendered uninhabitable by any considerable inclination of his axis.

but has four moons. 72. The Sun appears but $\frac{1}{28}$ part as large to Jupiter as to us; and his light and heat are in the same small proportion, but compensated by the quick returns thereof, and by four moons (some larger and some less than our Earth) which revolve about him: so that there is scarce any part of this huge planet, but what is, during the whole night, enlightened by one or more of these moons; except his poles, where only the farthest moons can be seen, and where light is not wanted; because the Sun constantly circulates in or near the horizon, and is very probably kept in view of both poles by the refraction of Jupiter's atmosphere, which, if it be like ours, has certainly refractive power enough for that purpose.

Their periods round Jupiter. 73. The orbits of these moons are represented in the scheme of the solar system by four small circles marked 1, 2, 3, 4, on Jupiter's orbit ♃; drawn, indeed, fifty times too large in proportion to it. The first moon, or that nearest to Jupiter, goes round him in 1 day 18 hours and 36 minutes of our time; and is 229 thousand miles distant from his centre: the second performs its revolution in 3 days 13 hours and 15 minutes, at 364 thousand miles distance: the third in 7 days 3 hours and 59 minutes, at the distance of 580 thousand miles: and the fourth, or outermost, in 16 days 18 hours and 30 minutes, at the distance of one million of miles from his centre.

Parallax of their orbits, and distances from Jupiter.

74. The angles under which the orbits of Jupiter's moons are seen from the Earth, at its mean distance from Jupiter, are as follows: The first, 3′ 55″; the second, 6′ 14″; the third, 9′ 58″; and the fourth, 17′ 30″. And their distances from Jupiter, measured by his semi-diameters, are thus: The first, $5\frac{2}{3}$; the second 9, the third, $14\frac{23}{60}$; and the fourth, $25\frac{18}{60}$*. This planet, seen from its nearest moon, appears 1000 times as large as our Moon does to us; waxing and waneing in all her monthly shapes, every $42\frac{1}{3}$ hours.

How he appears to his nearest moon.

Two grand discoveries made by the eclipses of Jupiter's moons.

75. Jupiter's three nearest moons fall into his shadow, and are eclipsed in every revolution: but the orbit of the fourth moon is so much inclined, that it passes by its opposition to Jupiter, without falling into his shadow, two years in every six. By these eclipses, astronomers have not only discovered that the Sun's light takes up eight minutes of time in coming to us; but they have also determined the longitudes of places on this Earth, with greater certainty and facility, than by any other method yet known; as shall be explained in the eleventh chapter.

The great difference between the equatorial and polar diameters of Jupiter.

76. The difference between the equatorial and polar diameters of Jupiter is 6230 miles; for his equatorial diameter is to his polar, as 13 to 12. So that his poles are 3115 miles nearer his centre than his equator is. This results from his quick motion round his axis; for the fluids, together with the light particles, which they can carry or wash away with them, recede from the poles, which are at rest, toward the equator, where the motion is quickest; until there be a sufficient number accumulated to make up the deficiency of gravity lost by the centrifugal force which always arises from a quick motion round an axis: and when the deficiency of weight or gravity of the particles is made up by a sufficient accumulation, there is an *equili-*

* Cassini *Elemens d'Astronomie*, *Liv. ix. Chap.* 3.

Plate I. *brium*, and the equatorial parts rise no higher. Our

The difference little in those of our Earth. Earth being but a very small planet, compared with Jupiter, and its motion round its axis being much slower, it is less flattened of course. The proportion between its equatorial and polar diameters being only as 230 to 229; and their difference 36 miles.*

Place of his nodes. 77. Jupiter's orbit is inclined to the ecliptic in an angle of 1 degree 20 minutes. His ascending node is in the 8th degree of Cancer, and his descending node in the 8th degree of Capricorn.

Saturn. 78. SATURN, the remotest of all the planets,† is about 780 millions of miles from the Sun; and travelling at the rate of 18 thousand miles every hour, in the circle marked ♄, performs its annual circuit in 29 years 167 days, and 5 hours of our time; which makes only one year to that planet. Its diameter is 67,000 miles; and therefore it is near 600 times as large as the Earth.

Fig. I.

His ring. Fig. V. 79. This planet is surrounded by a thin broad ring, as an artificial globe is by an horizon. The ring appears double when seen through a good telescope, and is represented, by the figure, in such an oblique view as that in which it generally appears. It is inclined 30 degrees to the ecliptic, and is about 21 thousand miles in breadth; which is equal to its distance from Saturn on all sides. There is reason to believe that the ring turns round its axis;

* According to the French measures, a degree of the meridian at the equator contains 340606.68 French feet; and a degree of the meridian in Lapland contains 344627.40: so that a degree in Lapland is 4020.72 French feet (or 4280.02 English feet) longer than a degree at the equator. The difference is $\frac{81}{100}$ parts of an English mile.—Hence, the Earth's equatorial diameter contains 39386196 French feet, or 41926356 English; and the polar diameter 39202920 French feet, or 41731272 English. The equatorial diameter therefore is 195084 English feet, or 36.948 English miles, longer than the axis.

† The Georgian planet was not discovered when this was written.

because, when it is almost edge-wise to us, it appears somewhat thicker on one side of the planet than on the other; and the thickest edge has been seen on different sides at different times*. Saturn having no visible spots on his body, whereby to determine the time of his turning round his axis, the length of his days and nights, and the position of his axis, are unknown to us†. *Plate I.*

80. To Saturn, the Sun appears only $\frac{1}{90}$th part as large as to us; and the light and heat he receives from the Sun are in the same proportion to ours. But to compensate for the small quantity of sunlight, he has five moons, all going round him on the out-side of his ring, and nearly in the same plane with it. The first, or nearest moon to Saturn, goes round him in 1 day 21 hours 19 minutes; and is 140 thousand miles from his centre: the second, in 2 days 17 hours 40 minutes; at the distance of 187 thousand miles. the third, in 4 days 12 hours 25 minutes; at 263 thousand miles distance: the fourth, in 15 days 22 hours 41 minutes; at the distance of 600 thousand miles: and the fifth, or outermost, at one million 800 thousand miles from Saturn's centre, goes round him in 79 days 7 hours 48 minutes‡. Their orbits, in the scheme of the solar sys- Fig. I.

His five moons.

* Dr. Herschel, from some spots he has seen on the exterior ring, has determined that it revolves in about 10 1-2 hours.

† Dr. Herschel having discovered that there are some belt-like appearances on this planet, similar to those which are seen on Jupiter, concluded that it must revolve on its axis, and that with a pretty quick motion. He also thinks he has determined, from some parts of those belts which are less black than others, that this revolution is performed in 10 hours 16 minutes.

‡ Dr. Herschel has discovered two other moons belonging to Saturn, which revolves between the nearest of the old ones and the planet; so that Saturn is now known to have seven moons. The exterior of the new satellites, called the sixth, revolves at the distance of near 120 thousand miles, in one day 8 hours 53 minutes; and that which is nearest the primary, termed the seventh, is distant from it about 91 thousand miles, and performs its revolution in 22 hours 37 minutes: but the Doctor esteems this last article rather uncertain. He has moreover discovered that the fifth satellite revolves on its

tem, are represented by the five small circles, marked 1, 2, 3, 4, 5, on Saturn's orbit; but these, like the orbits of the other satellites, are drawn fifty times too large in proportion to the orbits of their primary planets.

81. The Sun shines almost fifteen of our years together on one side of Saturn's ring without setting, and as long on the other, in its turn. So that the ring is visible to the inhabitants of that planet for almost fifteen of our years, and as long invisible, by turns, if its axis have no inclination to its ring: but if the axis of the planet be inclined to the ring, suppose about 30 degrees, the ring will appear and disappear once every natural day, to all the inhabitants within 30 degrees of the equator on both sides, frequently eclipsing the Sun in a Saturnian day. Moreover, if Saturn's axis be thus inclined to his ring, it is perpendicular to his orbit; and thereby the inconvenience of different seasons to that planet is avoided. For considering the length of Saturn's year, which is almost equal to 30 of ours, what a dreadful condition must the inhabitants of his polar regions be in, if they be half that time deprived of the light and heat of the Sun! which is not their case alone, if the axis of the planet be perpendicular to the ring, for then the ring must hide the Sun from vast tracts of land on each side of the equator for 13 or 14 of our years together, on the south side and north side, by turns, as the axis inclines to or from the Sun. This furnishes another good presumptive proof of the inclination of Saturn's axis to its ring, and also of his axis being perpendicular to its orbit.

His axis probably inclined to his ring.

82. This ring, seen from Saturn, appears like a vast luminous arch in the heavens, as if it did

How the ring appears to Saturn and to us.

axis, as our Moon does, in the same time it revolves in its orbit: a very remarkable as well as curious coincidence in the motions of the secondaries to two different, and very distant primaries. And it is probably a general law of nature, that all *secondary* planets constantly present the *same face* towards their *primaries*.

not belong to the planet. When we see the ring most open, its shadow upon the planet is broadest; and from that time the shadow grows narrower, as the ring appears to do to us; until by Saturn's annual motion the Sun comes to the plane of the ring, or even with its edge; which being then directed toward us, becomes invisible on account of its thinness; as shall be explained more largely in the tenth chapter, and illustrated by a figure. The ring disappears twice in every annual revolution of Saturn; namely, when he is in the 20th degrees of Pisces and of Virgo. And when Saturn is in the middle between these points, or in the 20th degree either of Gemini or of Sagittarius, his ring appears most open to us; and then its longest diameter is to its shortest, as 9 to 4.

In what signs Saturn appears to lose his ring, and in what signs it appears most open to us.

83. To such eyes as ours, unassisted by instruments, Jupiter is the only planet that can be seen from Saturn; and Saturn the only planet that can be seen from Jupiter. So that the inhabitants of these two planets must either see much farther than we do, or have equally good instruments to carry their sight to remote objects, if they know that there is such a body as our Earth in the universe, for the Earth is no larger, seen from Jupiter, than his moons are, seen from the Earth, and if his large body had not first attracted our sight, and prompted our curiosity to view him with a telescope, we should never have known any thing of his moons; unless indeed by chance, we had directed the telescope toward that small part of the heavens where they were, at the time of observation. And the like is true of the moons of Saturn.

No planet but Saturn can be seen from Jupiter; nor any from Saturn besides Jupiter.

84. The orbit of Saturn is 2½ degrees inclined to the ecliptic or orbit of our Earth, and intersects it in the 22d degrees of Cancer and of Capricorn; so that Saturn's nodes are only 14 degrees from those of Jupiter, § 77*.

Place of Saturn's nodes.

* Since Mr. Ferguson's death, a seventh primary planet, belonging to the solar system, has been discovered by Dr. Herschel, and *Georgium Sidus.*

The Sun's light much stronger on Jupiter and Saturn than is generally believed.

85. The quantity of light afforded by the Sun to Jupiter, being but $\frac{1}{27}$th part, and to Saturn only $\frac{1}{90}$th part of what we enjoy; may at first thought induce us to believe that these two planets are entirely unfit for rational beings to dwell upon. But, that their light is not so weak as we imagine, is evident from their brightness in the night-time; and also from this remarkable phenomenon,—that when the Sun is so

called by him, the *Georgium Sidus*, out of respect to his present Majesty King George the III. This planet is still higher in the system than Saturn, being about 1565 millions of miles from the Sun, and performs its annual circuit in 83 years, 140 days and 8 hours of our time: consequently its motion in its orbit, is at the rate of about 7 thousand miles in an hour. To a good eye unassisted by a telescope, this planet appears like a faint star of the 5th magnitude; and cannot be readily distinguished from a fixed star with a less magnifying power than 200 times. Its apparent diameter subtends an angle of no more than 4″ to an observer on the Earth; but its real diameter is about 34,000 miles, and consequently, it is about 80 times as large as the Earth. Hence we may infer that as the Earth cannot be seen under an angle of quite 1″ to the inhabitants of the Georgian planet, it has never yet been seen by them, unless their eyes and instruments are considerably better than ours.

The orbit of this planet is inclined to the ecliptic in an angle of 46′ 26″. Its ascending node is in the 13th degree of Gemini, and its descending node in the 13th degree of Sagittarius. As no spots have yet been discovered on its surface, the position of its axis, and the length of its day and night are not known.

On account of the immense distance of the Georgian planet from the source of light and heat to all the bodies in our system, it was highly probable that several satellites, or moons revolved round it: accordingly, the high powers of Dr. Herschel's telescopes have enabled him to discover six; and there may be others which he has not yet seen. The first, and nearest to the planet, revolves at the distance of 12 of the planet's semi-diameters from it, and performs its revolution in 5 days, 21 hours 25 minutes: the second revolves at 16 1-2 semi-diameters of the primary from it, and completes its revolution in 8 days 17 hours 1 minute: the third at 19 semi-diameters, in 10 days 23 hours 4 minutes: the fourth at 22 semi-diameters, in 13 days 11 hours 5 minutes: the 5th at 44 semi-diameters, in 38 days 1 hour 49 minutes: and the sixth at 88 semi-diameters, in 107 days 16 hours 40 minutes. It is remarkable that the orbits of these Satellites are almost at right angles to the plane of the ecliptic: and that the motion of all of them, in their orbits is retrograde.

much eclipsed to us, as to have only the 40th part of his disc left uncovered by the Moon, the decrease of light is not very sensible; and just at the end of darkness in total eclipses, when his western limb begins to be visible, and seems no bigger than a bit of fine silver wire, every one is surprised at the brightness wherewith that small part of him shines. The Moon, when full, affords travellers light enough to keep them from mistaking their way; and yet, according to Dr. SMITH*, it is equal to no more than a 90 thousandth part of the light of the Sun: that is, the Sun's light is 90 thousand times as strong as the light of the Moon when full. Consequently, the Sun gives a thousand times as much light to Saturn as the full Moon does to us, and above three thousand times as much to Jupiter. So that these two planets, even without any moons, would be much more enlightened than we at first imagine; and by having so many, they may be very comfortable places of residence. Their heat, so far as it depends on the force of the Sun's rays, is certainly much less than ours; to which no doubt the bodies of their inhabitants are as well adapted as ours are to the seasons we enjoy. And if we consider that Jupiter never has any winter, even at his poles, which probably is also the case with Saturn, the cold cannot be so intense on these two planets as is generally imagined. Besides, there may be something in the nature of their soil, that renders it warmer than that of our Earth; and we find that all our heat depends not on the rays of the Sun: for if it did, we should always have the same months equally hot or cold at their annual returns. But it is far otherwise, for *February* is sometimes warmer than *May;* which must be owing to vapours and exhalations from the Earth.

All our heat depends not on the Sun's rays.

86. Every person who looks upon, and compares the systems of moons together, which belong to

* Optics, Art. 95.

Jupiter and Saturn must be amazed at the vast magnitude of these two planets, and the noble attendance they have in comparison with our little Earth; and can never bring himself to think, that an infinitely wise Creator should dispose of all his animals and vegetables here, leaving the other planets bare and destitute of rational creatures. To suppose that he had any view to our benefit, in creating these moons, and giving them their motions round Jupiter and Saturn; to imagine that he intended these vast bodies for any advantage to us, when he well knew they could never be seen but by a few astronomers peeping through telescopes; and that he gave to the planets regular returns of days and nights, and different seasons to all where they would be convenient; but of no manner of service to us; except only what immediately regards our own planet the Earth. To imagine, I say, that he did all this on our account, would be charging him impiously with having done much in vain; and as absurd as to imagine that he has created a little sun and a planetary system within the shell of our Earth, and intended them for our use. These considerations amount to little less than a positive proof, that all the planets are inhabited; for if they be not, why all this care in furnishing them with so many moons, to supply those with light which are at the greater distances from the Sun? Do we not see that the farther a planet is from the Sun, the greater apparatus it has for that purpose? save only Mars, which being but a small planet, may have moons too small to be seen by us. We know that the Earth goes round the Sun, and turns round its own axis, to produce the vicissitudes of summer and winter by the former, and of day and night by the latter motion, for the benefit of its inhabitants. May we not then fairly conclude, by parity of reason, that the end or design of all the other planets is the same? and is not this agreeable to the beautiful harmony which exists throughout the universe? Surely it is: and this con-

It is highly probable that all the planets are inhabited.

sideration must raise in us the most magnificent ideas of the SUPREME BEING; who is every where, and at all times present; displaying his power, wisdom and goodness, among all his creatures; and distributing happiness to innumerable ranks of various beings! *Plate I.*

87. In Fig. II. we have a view of the proportional breadth of the Sun's face or disc, as seen from the different planets. The Sun is represented No. 1, as seen from Mercury; No. 2, as seen from Venus; No. 3, as seen from the Earth, No. 4, as seen from Mars; No. 5, as seen from Jupiter; and No. 6, as seen from Saturn. Fig II. How the Sun appears to the different planets.

Let the circle *B* be the Sun, as seen from any planet at a given distance: to another planet, at double that distance, the Sun will appear just of half that breadth, as *A*; which contains only one fourth part of the area or surface of *B*. For all circles, as well as square surfaces, are to one another as the squares of their diameters or sides. Thus the square *A* is just half as broad as the square *B*; and yet it is plain to sight, that *B* contains four times as much surface as *A*. Hence, by comparing the diameters of the above circles (Fig. II.) together, it will be found that in round numbers, the Sun appears 7 times larger to Mercury than to us, 90 times larger to us than to Saturn, and 630 times as large to Mercury as to Saturn. Fig III. Fig. IV.

88. In Fig. V. we have a view of the magnitudes of the planets, in proportion to each other, and to a supposed globe of two feet diameter for the Sun. The Earth is 27 times as large as Mercury, very little larger than Venus, 5 times as large as Mars; but Jupiter is 1049 times as large as the Earth, Saturn 586 times as large, exclusive of his ring; and the Sun is 877 thousand 650 times as large as the Earth. If the planets in this figure were set at their due distances from a Sun of two feet diameter, according to their proportionable magnitudes, as in our system, Mercury would be 28 yards from the Sun's centre; Venus 51 yards 1 foot; the Earth Fig. V. Proportional bulks and distances of the planets.

Plate I. 70 yards 2 feet; Mars 107 yards 2 feet; Jupiter 370 yards 2 feet; and Saturn 760 yards 2 feet. The comet of the year 1680, at its greatest distance, 10 thousand 760 yards. In this proportion, the Moon's distance from the centre of the Earth would be only $7\frac{1}{2}$ inches.

An idea of their distances. 89. To assist the imagination in forming an idea of the vast distances of the Sun, planets and stars, let us suppose that a body projected from the Sun should continue to fly with the swiftness of a cannon ball, *i. e.* 480 miles every hour; this body would reach the orbit of Mercury, in 7 years 221 days; of Venus, in 14 years 8 days; of the Earth, in 19 years 91 days; of Mars, in 29 years 85 days; of Jupiter, in 100 years 280 days; of Saturn, in 184 years 240 days; to the comet of 1680, at its greatest distance from the Sun, in 2660 years; and to the nearest fixed stars, in about 7 million 600 thousand years.

Why the planets appear greater and less at different times. 90. As the Earth is not in the centre of the orbits in which the planets move, they come nearer to it and go farther from it, at different times; on which account they appear greater and less by turns.— Hence, the apparent magnitudes of the planets are not always a certain rule to know them by.

91. Under fig. III. are the names and characters of the twelve signs of the zodiac, which the reader should be perfectly well acquainted with; so as to know the characters without seeing the names. Each sign

Fig. I. contains 30 degrees, as in the circle bounding the solar system; to which the characters of the signs are set in their proper places.

The comets 92. The COMETS are solid opaque bodies, with long transparent trains or tails, issuing from that side which is turned away from the Sun. They move about the Sun in very eccentric ellipses; and are of a much greater density than the Earth; for some of them are heated in every period to such a degree, as would vitrify or dissipate any substance known to us. Sir ISAAC NEWTON computed the

heat of the comet which appeared in the year 1680, when nearest the Sun, to be 2000 times hotter than red-hot iron; and that being thus heated, it must retain its heat until it comes round again; although its period should be more than twenty thousand years; though it is computed to be only 575. The method of computing the heat of bodies, keeping at any known distance from the Sun, so far as their heat depends on the force of the Sun's rays, is very easy; and shall be explained in the eighth chapter. *Plate I.*

93. Part of the paths of three comets is delineated in the scheme of the solar system, and the years marked in which they made their appearance.— There are, at least, 21 comets belonging to our system, moving in all sorts of directions; and all those which have been observed, have moved through the ethereal regions and the orbits of the planets, without suffering the least sensible resistance in their motions; which plainly proves that the planets do not move in solid orbits. Of all the comets, the periods of the above mentioned three only are known with any degree of certainty. The first of these comets appeared in the years 1531, 1607, and 1682; and is expected to appear again in the year 1758, and every 75th year afterward. The second of them appeared in 1532, and 1661, and may be expected to return in 1789, and every 129th year afterward. The third, having last appeared in 1680, and its period being no less than 575 years, cannot return until the year 2225. This comet, at its greatest distance, is about eleven thousand two hundred millions of miles from the Sun; and at its least distance from the Sun's centre, which is 49,000 miles, is within less than a third part of the Sun's semi-diameter from his surface. In that part of its orbit which is nearest the Sun, it flies with the amazing swiftness of 880,000 miles in an hour; and the Sun, as seen from it, appears a hundred degrees in breadth; consequently 40 thousand times as large as he ap-

Fig. I.

They prove that the orbits of the planets are not solid.

The periods only of three are known.

They prove the stars to be at immense distances.

pears to us. The astonishing length that this comet runs out into empty space, suggests to our minds an idea of the vast distance between the Sun and the nearest fixed stars; of whose attractions all the comets must keep clear, to return periodically, and go round the Sun; and it shews us also, that the nearest stars, which are probably those that seem the largest, are as big as our Sun, and of the same nature with him; otherwise, they could not appear so large and bright to us as they do at such an immense distance.

Inferences drawn from the above phenomena.

94. The extreme heat, the dense atmosphere, the gross vapours, the chaotic state of the comets, seem at first sight to indicate them altogether unfit for the purposes of animal life, and a most miserable habitation for rational beings; and therefore some* are of opinion that they are so many hells for tormenting the damned with perpetual vicissitudes of heat and cold. But when we consider, on the other hand, the infinite power and goodness of the Deity; the latter inclining, the former enabling him to make creatures suited to all states and circumstances; that matter exits only for the sake of intelligent beings; and that wherever we find it, we always find it pregnant with life, or necessarily subservient thereto; the numberless species, the astonishing diversity of animals in earth, air, water, and even on other animals; every blade of grass, every tender leaf, every natural fluid, swarming with life; and every one of these enjoying such gratifications as the nature and state of each requires: when we reflect, moreover, that some centuries ago, till experience undeceived us, a great part of the Earth was adjudged uninhabitable; the torrid zone, by reason of excessive heat, and the two frigid zones because of their intolerable cold; it seems highly probable, that such numerous and

* Mr. WHISTON, in his Astronomical Principles of Religion.

large masses of durable matter as the comets are, however unlike they be to our Earth, are not destitute of beings capable of contemplating with wonder, and acknowledging with gratitude, the wisdom, symmetry, and beauty of the creation; which is more plainly to be observed in their extensive tour through the heavens, than in our more confined circuit. If farther conjecture be permitted, may we not suppose them instrumental in recruiting the expended fuel of the Sun; and supplying the exhausted moisture of the planets? However difficult it may be, circumstanced as we are, to find out their particular destination, this is an undoubted truth, that wherever the Deity exerts his power, there he also manifests his wisdom and goodness.

95. THE SOLAR SYSTEM, here described, is not a late invention; for it was known and taught by the wise *Samian* philosopher PYTHAGORAS, and others among the ancients: but in latter times was lost, till the 15th century, when it was again restored by the famous *Polish* philosopher, NICHOLAUS COPERNICUS, born at *Thorn* in the year 1473. In this he was followed by the greatest mathematicians and philosophers that have since lived; as KEPLER, GALILEO, DESCARTES, GASSENDUS, and Sir ISAAC NEWTON; the last of whom has established this system on such an everlasting foundation of mathematical and physical demonstration, as can never be shaken; and none who understand him can hesitate about it.

This system very ancient and demonstrable.

96. In the *Ptolemean system*, the Earth was supposed to be fixed in the centre of the universe; and the Moon, Mercury, Venus, the Sun, Mars, Jupiter, and Saturn, to move round the Earth. Above the planets, this hypothesis placed the firmament of stars, and then the two crystalline spheres: all which were included in and received motion from the *primum mobile*, which constantly

The Ptolemean system absurd.

revolved about the Earth in 24 hours from east to west. But as this rude scheme was found incapable of standing the test of art and observation, it was soon rejected by all true philosophers; notwithstanding the opposition and violence of blind and zealous bigots.

The Tychonic system partly true, and partly false.

97. The *Tychonic system* succeeded the *Ptolomean*, but was never so generally received. In this the Earth was supposed to stand still in the centre of the universe or firmament of stars, and the Sun to revolve about it every 24 hours; the planets,—Mercury, Venus, Mars, Jupiter, and Saturn, going round the Sun in the times already mentioned. But some of TYCHO's disciples supposed the Earth to have a diurnal motion round its axis, and the Sun with all the above planets to go round the Earth in a year; the planets moving round the Sun in the aforesaid times. This hypothesis being partly true and partly false, was embraced by few; and soon gave way to the only true and rational system, restored by COPERNICUS, and demonstrated by Sir ISAAC NEWTON.

98. To bring the foregoing particulars into one point of view, with several others which follow, concerning the periods, distances, magnitudes, &c. of the planets, the following table is inserted.

A Table of the Periods, Revolutions, Magnitudes, &c. of the Planets, on the Supposition of the Sun's Parallax being 10″. For the distances from the Sun, as determined from observations of the transit of Venus, in the year 1761, see § 194.

Sun and Planets.	Annual period round the Sun.	Diurnal rotation on its axis.	Diameter in English miles	Mean diam. as seen fr. the Sun.	Mean distance from the Sun in English miles	Eccentricity of its orbit in miles.	Axis inclined to its orbit.	Orbit inclined to the ecliptic	Place of its aphelion.	Place of its ascending node.	Proportion of diameters.	Proportion of magnitude	Prop. of gravity on the surface.	Proportion of density.
Sun	—	25d. 6h.	763000	—	—	—	8° 0′	—	—	—	10000	877650	24	25.5
Mercury	87d. 23h.	Unknown	2600	20″	32,000,000	6,720,000	Unkn.	6° 54′	♐ 13° 8	♉ 14° 43′	34.1	.097	Unkn.	Unkn.
Venus	224d. 17h.	24d. 8h	7906	30″	59,000,000	413,000	75° 0′	3° 20′	♒ 4° 20	□ 13° 59′	103.5	1	Unkn.	Unkn.
Earth	365d. 6h	1d. 0h.	7970	21″	82,000,000	1,377,000	23° 29′	—	♑ 8° 1′	—	104.5	1	1	100
Moon	365d. 6h.	29d 12.11h	2180	6″	82,000,000	13,000	2° 10′	5° 18′	—	Variable.	28.5	.02	.34	123.5
Mars	686d. 6h.	24h. 40m	4444	11″	125,000,000	11,439,000	0° 0′	1° 52′	♍ 9° 10′	♉ 17° 17′	58.17	.2	Unkn.	Unkn.
Jupiter	4332d. 12h.	9h. 56m	81000	37″	426,000,000	20,352,000	0° 0′	1° 20′	♎ 27° 50′	♋ 7° 29′	106.67	1049	2	19
Saturn	10759d. 7h.	10h. 16m	67000	16″	780,000,000	42,735,000	Unkn	2° 30′	♐ 27° 50′	♋ 21° 13′	878.11	586	1.5	15
Georgian	30456d. 2h.	Unknown	35000	9,9″	1565,000,000	74,404,000	Unkn.	0° 46′	♓ 13° 12′	□ 12° 48′	448.43	79.67	1.17	22

Sun and Planets.	Proportion of light & heat.	Propor. quantity of matter.	Hourly motion in its orbit.	Hourly motion of its equator.	Square miles in surface.	Cubic miles in solidity.	Projectile force being destroyed, would fall to the Sun in: days	hours
Sun	4500	227500	—	3818	1,828,911,000,000	232,577,115,137,000,000		
Mercury	6.5	Unkn.	95000	Unkn.	21,236,800	9,195,534,500	15	13
Venus	1	Unkn.	69000	43	691,351,300	258,507,832,200	39	17
Earth	1	1	58000	1042	199,859,860	265,404,598,080	64	10
Moon	13+	.43	2290	9.5	14,898,750	5,408,246,000	64	10
Mars	.43	Unkn.	47000	556	62,088,240	45,969,335,840	121	0
Jupiter	.036	220	25000	25920	20,603,970,000	278,153,595,000,000	290	0
Saturn	.011	94	18000	20493	14,102,562,000	155,128,182,000,000	767	0
Georgian	.0029	18	7000	Unkn.	3,678,183,000	20,976,679,225,000	1307	0

Moons.	Periods round Jupiter.			Periods round Saturn.			Periods round the Georgian.		
N°.	D.	H.	M.	D.	H.	M.	D.	H.	M.
1	1	18	35	1	21	19	5	21	25
2	3	13	19	2	17	40	8	17	1
3	7	3	5	4	12	25	10	23	4
4	19	18	50	15	22	41	12	11	5
5				79	7	48	31	1	49
6				1	8	53	107	16	40
7				0	22	37			

The Moon belonging to the Earth goes round its orbit in 27 days, 7 hours, 43 minutes.

☞ Since the year 1800, there have been discovered three very small celestial bodies, revolving round the Sun, in elliptical orbits, of considerable eccentricity, situate between the orbits of Mars and of Jupiter. Dr. Herschell has given them the general appellation of *asteroids*. They have been particularly designated by the mythological names of Ceres, Pallas, and Juno; but M. de la Lande, with more justice and reason, chooses to name them after their first discoverers—Piazzi, Olbers, and Harding.——☞ A *fourth*, it is said, has been lately discovered, also, between the orbits of Mar's and Jupiter.

CHAP. III.

The COPERNICAN SYSTEM *demonstrated to be true.*

Of matter and motion.

99. MATTER is of itself inactive, and indifferent to motion or rest. A body at rest can never put itself in motion; a body in motion can never stop or move slower of itself. Hence, when we see a body in motion, we conclude that some other substance must have given it that motion; when we see a body fall from motion to rest we conclude that has some other body or cause stopt it.

100. All motion is naturally rectilineal. A bullet thrown by the hand, or discharged from a cannon, would continue to move in the same direction it received at first, if no other power diverted its course. Therefore, when we see a body moving in a curve of whatever kind, we conclude it must be acted upon by two powers at least: one to put it in motion, and another drawing it off from the rectilineal course which it would otherwise have continued to move in.

Gravity demonstrable.

101. The power by which bodies fall toward the Earth, is called *gravity* or *attraction.* By this power in the Earth it is, that all bodies on whatever side, fall in lines perpendicular to its surface. On opposite parts of the Earth, bodies fall in opposite directions;—all toward the centre, where the whole force of gravity is, as it were, accumulated. By this power constantly acting on bodies near the Earth, they are kept from leaving it altogether; and those on its surface are kept there on all sides, so that they cannot fall from it. Bodies thrown with any obliquity are drawn, by this power, from a straight line into a curve, until they fall to the ground: the greater the force by which they are thrown, the greater is the distance they are carried before they fall. If we suppose a body carried se-

veral miles above the Earth, and there projected in a horizontal direction, with so great a velocity, that it would move more than a semidiameter of the Earth in the time it would take to fall to the Earth by gravity; in that case, if there were no resisting medium in the way, the body would not fall to the Earth at all, but continue to circulate round the Earth, keeping always the same path, and returning to the point from whence it was projected, with the same velocity as at first.

102. We find that the Moon moves round the Earth in an orbit nearly circular. The Moon therefore must be acted on by two powers or forces: one, which would cause her to move in a right line; another, bending her motion from that line into a curve. This attractive power must be seated in the Earth, for there is no other body within the Moon's orbit to draw her. The attractive power of the Earth therefore extends to the Moon; and, in combination with her projectile force, causes her to move round the Earth, in the same manner as the circulating body above supposed. Projectile force demonstrable.

103. The moons of Jupiter and Saturn are observed to move round their primary planets: therefore there is an attractive power in these planets. All the planets move round the Sun, and respect it for their centre of motion: therefore the Sun must be endowed with an attracting power, as well as the Earth and planets. The like may be proved of the comets. So that all the bodies or matter of the solar system, are possessed of this power; and so perhaps is all matter universally. The Sun and planets attract each other.

104. As the Sun attracts the planets with their satellites, and the Earth the Moon; so the planets and satellites re-attract the Sun, and the Moon the Earth; action and re-action being always equal. This is also confirmed by observation; for the Moon raises tides in the ocean, and the satellites and planets disturb one another's motions.

105. Every particle of matter being possessed of an attracting power, the effect of the whole must be in proportion to the number of attracting particles: that is, to the quantity of matter in the body. This is demonstrated from experiments on pendulums: for, when they are of equal lengths, whatever their weights be, they always vibrate in equal times. Now, if one be double the weight of another, the force of gravity or attraction must be double to make it oscillate with the same celerity; if one have thrice the weight or quantity of matter of another, it requires thrice the force of gravity to make it move with the same celerity. Hence it is certain, that the power of gravity is always proportional to the quantity of matter in bodies, whatever may be their magnitudes or figures.

106. Gravity also, like all other virtues or emanations, either drawing or impelling a body toward the centre, decreases as the square of the distance increases: that is, a body at twice the distance attracts another with only a fourth part of the force; at four times the distance, with a sixteenth part of the force, &c. This too is confirmed from observation, by comparing the distance which the Moon falls in a minute from a right line touching her orbit, with the space which bodies near the Earth fall in the same time: and also by comparing the forces which retain Jupiter's moons in their orbits: as will be more fully explained in the seventh chapter.

Gravitation and projection exemplified.

107. The mutual attraction of bodies may be exemplified by a boat and a ship on the water, tied together by a rope. Let a man either in the ship or boat pull the rope (it is the same in effect at which end he pulls, for the rope will be equally stretched throughout) the ship and boat will be drawn toward one another; but with this difference, that the boat will move as much faster than the ship, as the ship is heavier than the boat. Suppose the boat as heavy as the ship, and they will draw one

another equally, (setting aside the greater resistance of the water on the larger body) and meet in the middle of the first distance between them. If the ship be a thousand or ten thousand times heavier than the boat, the boat will be drawn a thousand or ten thousand times faster than the ship; and meet proportionably nearer the place from which the ship set out. Now, while one man pulls the rope, endeavouring to bring the ship and boat together, let another man in the boat, endeavour to row it off sideways, or at right angles to the rope; and the former, instead of being able to draw the boat to the ship, will find it enough for him to keep the boat from going further off; while the latter endeavouring to row off the boat in a straight line, will, by means of the other's pulling it toward the ship, row the boat round the ship at the rope's length from her. Here the power employed to draw the ship and boat to one another represents the mutual attraction of the Sun and planets by which the planets would fall freely toward the Sun with a quick motion; and would also in falling attract the Sun toward them. And the power employed to row off the boat, represents the projectile force impressed on the planets, at right angles, or nearly so, to the Sun's attraction; by which means the planets move round the Sun, and are kept from falling to it. On the other hand, if it be attempted to make a heavy ship go round a light boat, they will meet sooner than the ship can get round; or the ship will drag the boat after it.

108. Let the above principles be applied to the Sun and Earth; and they will evince, beyond a possibility of doubt, that the Sun, not the Earth, is the centre of the system; and that the Earth moves round the Sun as the other planets do.

For, if the Sun move about the Earth, the Earth's attractive power must draw the Sun toward it, from the line of projection, so as to bend its motion into a curve. But the Sun being at least

227 thousand times as heavy as the Earth, being so much heavier as its quantity of matter is greater, it must move 227 thousand times as slowly toward the Earth, as the Earth does toward the Sun; and consequently the Earth would fall to the Sun in a short time, if it had not a very strong projectile motion to carry it off. The Earth therefore, as well as every other planet in the system, must have a rectilineal impulse, to prevent its falling to the Sun. To say, that gravitation retains all the other planets in their orbits, without affecting the Earth, which is placed between the orbits of Mars and Venus, is as absurd as to suppose that six cannon bullets might be projected upward to different heights in the air; and that five of them should fall down to the ground, but the sixth, which is neither the highest nor the lowest should remain suspended in the air without falling, and the Earth move round about it.

The absurdity of supposing the Earth at rest.

109. There is no such thing in nature as a heavy body moving round a light one, as its centre of motion. A pebble fastened to a mill-stone, by a string, may, by an easy impulse, be made to circulate round the mill-stone; but no impulse whatever can make a mill-stone circulate round a loose pebble; for the mill-stone would go off, and carry the pebble along with it.

110. The Sun is so immensely greater and heavier than the Earth,* that if he were moved out of his place, not only the Earth, but all the other planets, if they were united into one mass, would be carried along with the Sun, as the pebble would be, with the mill-stone.

111. By considering the law of gravitation which takes place throughout the solar system, in another light, it will be evident, that the Earth moves round the Sun in a year; and not the Sun round the Earth. It has been shewn (§ 106) that the

* As will be demonstrated in the ninth chapter.

power of gravity decreases as the square of the distance increases; and from this it follows, with mathematical certainty, that when two or more bodies move round another as their centre of motion, the squares of their periodic times will be to one another in the same proportion as the cubes of their distances from the central body. This holds precisely with regard to the planets round the Sun, and the satellites round the planets; the relative distances of all which are well known. But, if we suppose the Sun to move round the Earth, and compare its period with the Moon's by the above rule, it will be found that the Sun would take no less than 173,510 days to move round the Earth; in which case our year would be 475 times as long as it now is. To this we may add, that the aspects of increase and decrease of the planets, the times of their seeming to stand still, and to move direct and retrograde, answer precisely to the Earth's motion; but not at all to the Sun's, without introducing the most absurd and monstrous suppositions, which would destroy all harmony, order, and simplicity in the system. Moreover, if the Earth be supposed to stand still, and the stars to revolve in free space about the Earth in 24 hours, it is certain that the forces by which the stars revolve in their orbits are not directed to the Earth, but to the centres of the several orbits; that is, of the several parallel circles which the stars on different sides of the equator describe every day; and the like inferences may be drawn from the supposed diurnal motion of the planets, since they are never in the equinoctial but twice in their courses with regard to the starry heavens. But, that forces should be directed to no central body, on which they physically depend, but to innumerable imaginary points in the axis of the Earth produced to the poles of the heavens, is a hypothesis too absurd to be allowed of by any rational creature. And it is still more ab-

The harmony of the celestial motions.

The absurdity of supposing the stars and planets to move round the Earth.

surd to imagine that these forces should increase exactly in proportion to the distances from this axis; for that is an indication of an increase to infinity; whereas the force of attraction is found to decrease in receding from the fountain from whence it flows. But the farther any star is from the quiescent pole, the greater must be the orbit which it describes; and yet it appears to go round in the same time as the nearest star to the pole does. And if we take into consideration the two-fold motion observed in the stars, one diurnal round the axis of the Earth in 24 hours, and the other round the axis of the ecliptic in 25920 years, § 251, it would require an explication of such a perplexed composition of forces, as could by no means be reconciled with any physical theory.

Objections against the Earth's motion answered. 112. There is but one objection of any weight that can be made against the Earth's motion round the Sun, which is, that in opposite points of the Earth's orbit, its axis, which always keeps a parallel direction, would point to different fixed stars; which is not found to be fact. But this objection is easily removed, by considering the immense distance of the stars in respect to the diameter of the Earth's orbit; the latter being no more than a point when compared to the former. If we lay a ruler on the side of a table, and along the edge of the ruler view the top of a spire at ten miles distance, and then lay the ruler on the opposite side of the table in a parallel situation to what it had before, the spire will still appear along the edge of the ruler, because our eyes, even when assisted by the best instruments, are incapable of distinguishing so small a change at so great a distance.

113. Dr. BRADLEY found, by a long series of the most accurate observations, that there is a small apparent motion of the fixed stars, occasioned by the aberration of their light, and so exactly answering to

an annual motion of the Earth, as evinces the same, even to a mathematical demonstration. Those who are qualified to read the Doctor's modest account of this great discovery, may consult the *Philosophical Transactions*, No. 406. Or they may find it treated of at large by Drs. SMITH*, LONG†, DESAGULIERS‡, RUTHERFURTH||, Mr. MACLAURIN, Mr. SIMPSON§, and M. DE LA CAILLE**.

114. It is true that the Sun seems to change his place daily, so as to make a tour round the starry heavens in a year. But whether the Sun or Earth moves, this appearance will be the same; for, when the Earth is in any part of the heavens, the Sun will appear in the opposite. And therefore this appearance can be no objection against the motion of the Earth.

Why the Sun appears to change his place.

115. It is well known to every person who has sailed on smooth water, or been carried by a stream in a calm, that, however fast the vessel goes, he does not feel its progressive motion. The motion of the Earth is incomparably more smooth and uniform than that of a ship, or any machine made and moved by human art: and therefore it is not to be imagined that we can feel its motion.

116. We find that the Sun, and those planets on which there are visible spots, turn round their axes: for the spots move regularly over their discs. From hence we may reasonably conclude, that the other planets on which we see no spots, and the Earth, which is likewise a planet, have such rotations. But being incapable of leaving the Earth, and viewing it at a distance, and its rotation being smooth and uniform, we can neither see it move

The Earth's motion on its axis demonstrated.

* Optics, B. I. § 1178. † Astronomy, B. II. § 838.
‡ Philosophy, vol I. p. 401. || Account of Sir Isaac Newton's *Philosophical Discoveries*, B. III. c. 2. § 3.
§ Mathemat. Essays, p. 1. ** *Elements d' Astronomie*, § 381.

on its axis as we do the planets, nor feel ourselves affected by its motion. Yet there is *one* effect of such a motion, which will enable us to judge with certainty whether the Earth revolves on its axis or not. All globes which do not turn round their axes will be perfect spheres, on account of the equality of the weight of bodies on their surfaces; especially of the fluid parts. But all globes which turn on their axes will be oblate spheroids; that is, their surfaces will be higher or farther from the centre in the equatorial than in the polar regions; for, as the equatorial parts move quickest, they will recede farthest from the axis of motion, and enlarge the equatorial diameter. That our Earth is really of this figure, is demonstrable from the unequal vibrations of a pendulum, and the unequal lengths of degrees in different latitudes. Since then the Earth is higher at the equator than at the poles, the sea, which naturally runs downward, or toward the places which are nearest the centre, would run toward the polar regions, and leave the equatorial parts dry, if the centrifugal force of these parts by which the waters were carried thither did not keep them from returning. The Earth's equatorial diameter is 36 miles longer than its axis.

All bodies heavier at the poles than they would be at the equator.

117. Bodies near the poles are heavier than those toward the equator, because they are nearer the Earth's centre, where the whole force of the Earth's attraction is accumulated. They are also heavier, because their centrifugal force is less, on account of their diurnal motion being slower. For both these reasons, bodies carried from the poles toward the equator gradually lose of their weight. Experiments prove that a pendulum which vibrates seconds near the poles, vibrates slower near the equator; which shews, that it is lighter or less attractive there. To make it oscillate in the same time, it is found necessary to diminish its length. By comparing the different lengths of pendulums

swinging seconds at the equator and at *London*, it is found that a pendulum must be $2\frac{168}{1000}$ lines, or 12th part of an inch shorter at the equator than at the poles.

How they might lose all their weight.

118. If the Earth turned round its axis in 84 minutes 43 seconds, the centrifugal force would be equal to the power of gravity at the equator; and all bodies there would entirely lose their weight. If the Earth revolved quicker, they would all fly off, and leave it.

The Earth's motion cannot be felt.

119. A person on the Earth can no more be sensible of its undisturbed motion on its axis, than one in the cabin of a ship, on smooth water, can be sensible of the ship's motion when it turns gently and uniformly round. It is therefore no argument against the Earth's diurnal motion, that we do not feel it: nor is the apparent revolutions of the celestial bodies every day a proof of the reality of these motions; for whether we or they revolve, the appearance is the very same. A person looking through the cabin-windows of a ship, as strongly fancies the objects on land to go round when the ship turns, as if they were actually in motion.

To the different planets the heavens appear to turn round on different axes.

120. If we could translate ourselves from planet to planet, we should still find that the stars would appear of the same magnitudes, and at the same distances from each other, as they do to us on the Earth, because the diameter of the remotest planet's orbit bears no sensible proportion to the distance of the stars. But then, the heavens would seem to revolve about very different axes; and consequently, those quiescent points, which are our poles in the heavens, would seem to revolve about other points, which, though apparently in motion as seen from the Earth, would be at rest as seen from any other planet. Thus the axis of Venus which lies almost at right angles to the axis of the Earth, would have its motionless poles in two opposite points of the heavens, lying almost in our equi-

noctial, where the motion appears quickest; because it is seemingly performed in the greatest circle. And the very poles which are at rest to us, have the quickest motion of all as seen from Venus. To Mars and Jupiter, the heavens appear to turn round with very different velocities on the same axis, whose poles are about 23½ degrees from ours. Were we on Jupiter, we should be at first amazed at the rapid motion of the heavens; the Sun and stars going round in 9 hours 56 minutes. Could we go from thence to Venus, we should be as much surprised at the slowness of the heavenly motions; the Sun going but once round in 584 hours, and the stars in 540. And could we go from Venus to the Moon, we should see the heavens turn round with a yet slower motion; the Sun in 708 hours, the stars in 655. As it is impossible these various circumvolutions in such different times, and on such different axes, can be real, so it is unreasonable to suppose the heavens to revolve about our Earth, more than it does about any other planet. When we reflect on the vast distance of the fixed stars, to which 162,000,000 of miles, the diameter of the Earth's orbit, is but a point, we are filled with amazement at the immensity of their distance. But if we try to frame an idea of the extreme rapidity with which the stars must move, if they move round the Earth in 24 hours, the thought becomes so much too big for our imagination, that we can no more conceive it than we do infinity or eternity. If the Sun were to go round the Earth in 24 hours, he must travel upward of 300,000 miles in a minute: but the stars being at least 400,000 times as far from the Sun as the Sun is from us, those about the equator must move 400,000 times as quick. And all this to serve no other purpose than what can be as fully and much more simply obtained by the Earth's turning round eastward, as on an axis, every 24 hours; causing thereby an apparent

diurnal motion of the Sun westward, and bringing about the alternate returns of day and night.

121. As to the common objections against the Earth's motion on its axis, they are all easily answered, and set aside. That it may turn without being seen or felt by us to do so, has been already shewn, § 119. But some are apt to imagine that if the Earth turns eastward (as it certainly does, if it turns at all) a ball fired perpendicularly upward in the air must fall considerably westward of the place it was projected from. This objection, which at first seems to have some weight, will be found to have none at all, when we consider that the gun and ball partake of the Earth's motion; and therefore the ball being carried forward with the air as quick as the Earth and air turn, must fall down on the same place. A stone let fall from the top of a main-mast, if it meet with no obstacle, falls on the deck as near the foot of the mast when the ship sails as when it does not. If an inverted bottle full of liquor, be hung up to the ceiling of the cabin, and a small hole be made in the cork to let the liquor drop through on the floor, the drops will fall just as far forward on the floor when the ship sails as when it is at rest. And gnats or flies can as easily dance among one another in a moving cabin, as in a fixed chamber. As for those scripture-expressions which seem to contradict the Earth's motion, the following reply may be made to them all: It is plain, from many instances, that the Scriptures were never intended to instruct us in philosophy or astronomy; and therefore, on those subjects, expressions are not always to be taken in the literal sense; but for the most part as accommodated to the common apprehensions of mankind. Men of sense in all ages, when not treating of the sciences purposely, have followed this method: and it would be in vain to follow any other in addressing ourselves to the vulgar, or bulk of any

Objections against the Earth's turn... answered.

community. *Moses* calls the Moon a GREAT LUMINARY (as it is in the Hebrew) as well as the Sun: but the Moon is known to be an opaque body, and the smallest that astronomers have observed in the heavens; and that it shines upon us, not by any inherent light of its own, but by reflecting the light of the Sun. *Moses* might know this; but had he told the *Israelites* so, they would have stared at him; and considered him rather as a madman, than as a person commissioned by the Almighty to be their leader.

CHAP. IV.

The Phenomena of the Heavens as seen from different Parts of the Earth.

We are kept to the Earth by gravity.

122. WE are kept to the Earth's surface, on all sides, by the power of its central attraction; which laying hold of all bodies according to their densities or quantities of matter, without regard to their bulks, constitutes what we call their *weight*. And having the sky over our heads, go where we will, and our feet toward the centre of the Earth; we call it *up* over our heads, and *down* under our feet: although the same right line which is *down* to us, if continued through and beyond the opposite side of the Earth, would be *up* to the inhabitants on the opposite side. For, the inhabitants *n*, *i*, *e*, *m*, *s*, *o*, [illegible] with their feet toward the Earth's centre *C*; and have the same figure of sky *N*, *I*, *E*, *M*, *S*, *O*, *Q*, *L*, over their heads. Therefore, the point *S* is as directly upward to the inhabitant *s* on the south pole, as *N* is to the inhabitant *n* on the north pole: so is *E* to the inhabitant *e* supposed to be on the north end of *Peru*; and *Q* to the opposite inhabitant *q* on the middle of the island *Sumatra*. Each of these observers is surprised that his opposite or *antipode* can stand with his head hanging downward. But let either

Plate II. Fig. 1.

Antipodes.

go to the other, and he will tell him that he stood as upright and firm on the place where he was, as he now stands where he is. To all these observers, the Sun, Moon, and stars, seem to turn round the points *N* and *S*, as the poles of the fixed axis *NCS*; because the Earth does really turn round the mathematical line *n C s* as round an axis of which *n* is the north pole, and *s* the south pole. The inhabitant *U* (Fig. II.) affirms that he is on the uppermost side of the Earth, and wonders how another at *L* can stand at the undermost side, with his head hanging downwards. But *U* in the mean time forgets, that in twelve hours time he will be carried half round with the Earth, and then be in the very situation that *L* now is; although as far from him as before; and yet, when *U* comes there, he will find no difference as to his manner of standing; only he will see the opposite half of the heavens, and imagine the heavens to have gone half round the Earth.

Plate II

Axis of the world.

Its poles.

Fig. II.

123. When we see a globe hung up in a room, we cannot help imagining it to have an upper and an under side, and immediately form a like idea of the Earth; from whence we conclude, that it is as impossible for people to stand on the under side of the Earth, as for pebbles to lie on the under side of a common globe, which instantly fall down from it to the ground; and well they may, because the attraction of the Earth being greater than the attraction of the globe, pulls them away. Just so would it be with our Earth, if it were fixed near a globe much bigger than itself, such as Jupiter: for then, it would really have an upper and an under side with respect to that large globe; which, by its attraction, would pull away every thing from the side of the Earth next to it; and only those bodies on its surface, at the opposite side, could remain upon it. But there is no larger globe near enough our Earth to overcome its

How our Earth might have an upper and an under side.

M

Plate II. central attraction, and therefore it has no such thing as an upper and an under side; for all bodies on or near its surface, even to the Moon, gravitate toward its centre.

124. Let any man imagine the Earth, and every thing but himself, to be taken away, and he left alone in the midst of indefinite space; he could then have no idea of *up* or *down*; and were his pockets full of gold, he might take the pieces one by one, and throw them away on all sides of him, without any danger of losing them; for the attraction of his body would bring them all back by the ways they went, and *he* would be *down* to every one of them. But then, if a sun, or any other large body, were created and placed in any part of space, several millions of miles from him, he would be attracted toward it, and could not save himself from falling *down* to it.

Fig. I

125. The Earth's bulk is but a point, as that at *C*, compared to the heavens; and therefore every inhabitant upon it, let him be where he will, as at *n*, *e*, *m*, *s*, &c. sees half of the heavens. The inhabitant *n*, on the north pole of the Earth, constantly sees the hemisphere *E N Q*; and having the north pole *N* of the heavens just over his head, his horizon coincides with the celestial equator *E C Q*. Therefore all the stars in the northern hemisphere *E N Q*, between the equator and north pole, appear to turn round the line *N C*, moving parallel to the horizon. The equatorial stars keep in the horizon, and all those in the southern hemisphere *E S Q* are invisible. The like phenomena are seen by the observer *s* on the south pole, with respect to the hemisphere *E S Q*; and to him the opposite hemisphere is always invisible. Hence, under either pole, only

Half of the heavens visible to an inhabitant on any part of the Earth.

one half of the heavens is seen; for those parts which are once visible never set, and those which are once invisible never rise. But the ecliptic *♈ C ♎*, or orbit which the Sun appears to describe once a year by the Earth's annual motion, has the half *♈ C* constantly above the horizon *E C Q* of the north pole *n*; and the other half *C ♎* always below it. Therefore while the Sun describes the northern half *♈ C* of the ecliptic, he neither sets to the north pole, nor rises to the south; and while he describes the southern half *C ♎*, he neither sets to the south pole, nor rises to the north. The same things are true with respect to the Moon; only with this difference, that as the Sun describes the ecliptic but once a year, he is for half that time visible to each pole in its turn, and as long invisible; but as the Moon goes round the ecliptic in 27 days 8 hours, she is only visible for 13 days 16 hours, and as long invisible to each pole by turns. All the planets likewise rise and set to the poles, because their orbits are cut obliquely in halves by the horizon of the poles. When the Sun (in his apparent way from *♎*) arrives at *C*, which is on the 20th of *March*, he is just rising to an observer at *n*, on the north pole, and setting to another at *s*, on the south pole. From *C* he rises higher and higher in every apparent diurnal revolution, till he comes to the highest point of the ecliptic *y*, on the 21st of *June*; when he is at his greatest altitude, which is 23½ degrees, or the arc *E y*, equal to his greatest north declination; and from thence he seems to descend gradually in every apparent circumvolution, till he sets at *C* on the 23d of *September*; and then he goes to exhibit the like appearances at the south pole for the other half of the year. Hence the Sun's apparent motion round the Earth is not in parallel circles, but in spirals; such as might be represented by a thread wound round a globe from tropic to tropic; the spirals being at some distance from one an-

Phenomena at the poles.

Plate II. other about the equator, and gradually nearer to each other as they approach toward the tropics.

Phenomena at the equator. 126. If the observer be any where on the terrestrial equator $e\ C\ q$, as suppose at e, he is in the plane of the celestial equator; or under the equinoctial $E\ C\ Q$; and the axis of the Earth $n\ C\ s$ is coincident with the plane of his horizon, extended out to N and S, the north and south poles of the heavens. Fig. I. As the Earth turns round the line $N\ C\ S$, the whole heavens $M\ O\ L\ l$ seem to turn round the same line, but the contrary way. It is plain that this observer has the celestial poles constantly in his horizon, and that his horizon cuts the diurnal paths of all the celestial bodies perpendicularly, and in halves. Therefore the Sun, planets, and stars, rise every day, ascend perpendicularly above the horizon for six hours, and, passing over the meridian, descend in the same manner for the six following hours; then set in the horizon, and continue twelve hours below it. Consequently at the equator the days and nights are equally long throughout the year. When the observer is in the situation e, he sees the hemisphere $S\ E\ N$, but in twelve hours after, he is carried half round the Earth's axis to q, and then the hemisphere $S\ Q\ N$ becomes visible to him, and $S\ E\ N$ disappears. Thus we find, that to an observer at either of the poles, one half of the sky is always visible, and the other half never seen; but to an observer on the equator the whole sky is seen every 24 hours.

The figure here referred to, represents a celestial globe of glass, having a terrestrial globe within it: after the manner of the glass sphere invented by my generous friend Dr. LONG, *Lowndes*'s Professor of Astronomy in *Cambridge*.

Remark. 127. If a globe be held sidewise to the eye, at some distance, and so that neither of its poles can be seen, the equator $E\ C\ Q$, and all circles parallel to it, as $D\ L$, $y\ z\ x$, $a\ b\ X$, $M\ O$, &c. will appear to be

straight lines, as projected in this figure; which is requisite to be mentioned here, because we shall have occasion to call them circles in the following articles of this chapter*.

128. Let us now suppose that the observer has gone from the equator *e* toward the north pole *n*, and that he stops at *i*, from which place he then sees the hemisphere *MEiNL*; his horizon *MCL* having shifted as many degrees from the celestial poles *N* and *S*, as he has travelled from under the equinoctial *E*. And as the heavens seem constantly to turn round the line *NCS* as an axis, all those stars which are not as many degrees from the north pole *N* as the observer is from the equinoctial, namely, the stars north of the dotted parallel *DL*, never set below the horizon; and those which are south of the dotted parallel *MO* never rise above it. Hence the former of these two parallel circles is called *the circle of perpetual apparition*, and the latter *the circle of perpetual occultation*: but all the stars between these two circles rise and set every day. Let us imagine many circles to be drawn between these two, and parallel to them; those which are on the north side of the equinoctial will be unequally cut by the horizon *MCL*, having larger portions above the horizon than below it: and the more so, as they are nearer to the circle of perpetual apparition; but the reverse happens to those on the south side of the equinoctial while the equinoctial is divided in two equal parts by the horizon. Hence, by the apparent turning of the heavens, the northern stars describe greater arcs or portions of circles above the horizon than below it; and the greater, as they are farther from the equinoctial toward the circle of perpetual apparition; while the contrary happens to all stars

Phenomena between the equator and poles.

The circles of perpetual apparition and occultation.

* The plane of a circle, or a thin circular plate, being turned edgewise to the eye, appears to be a straight line.

south of the equinoctial; but those upon it describe equal arcs both above and below the horizon, and therefore they are just as long above it as below it.

129. An observer on the equator has no circle of perpetual apparition or occultation, because all the stars, together with the Sun and Moon, rise and set to him every day. But, as a bare view of the figure is sufficient to shew that these two circles *DL* and *MO* are just as far from the poles *N* and *S* as the observer at *t* (or one opposite him at *o*,) is from the equator *ECQ*; it is plain, that if an observer begins to travel from the equator toward either pole, his circle of perpetual apparition rises from that pole as from a point, and his circle of perpetual occultation from the other. As the observer advances toward the nearer pole, these two circles enlarge their diameters, and come nearer to one another, until he comes to the pole; and then they meet and coincide in the equinoctial. On different sides of the equator, to observers at equal distances from it, the circle of perpetual apparition to one is the circle of perpetual occultation to the other.

Why the stars always describe the same parallel of motion, and the Sun a different.

130. Because the stars never vary their distances from the equinoctial, so as to be sensible in an age, the lengths of their diurnal and nocturnal arcs are always the same to the same places on the Earth. But as the Earth goes round the Sun every year in the ecliptic, one half of which is on the north side of the equinoctial, and the other half on its south side, the Sun appears to change his place every day: so as to go once round the circle *YCX* every year, § 114. Therefore while the Sun appears to advance northward, from having described the parallel *a b X* touching the ecliptic in *X*, the days continually lengthen and the nights shorten, until he comes to *y*, and describes the parallel *y z x*; when the days are at the longest and the nights at the shortest: for then

as the Sun goes no farther northward, the greatest portion that is possible of the diurnal arc $y\ z$ is above the horizon of the inhabitant *i;* and the smallest portion $z\ x$ below it. As the Sun declines southward from y, he describes smaller diurnal and greater nocturnal arcs or portions of circles every day; which causes the days to shorten and the nights to lengthen, until he arrives again at the parallel *a b X;* which having only the small part *a b* above the horizon *M C L*, and the great part *b X* below it, the days are at the shortest and the nights at the longest: because the Sun recedes no farther south, but returns northward as before. It is easy to see that the Sun must be in the equinoctial *E C Q* twice every year, and then the days and nights are equally long; that is, 12 hours each. These hints serve at present to give an idea of some of the appearances resulting from the motions of the Earth: which will be more particularly described in the tenth chapter. *Plate II.*

131. To an observer at either pole, the horizon and equinoctial are coincident; and the Sun and stars seem to move parallel to the horizon: therefore such an observer is said to have a *parallel* position of the sphere. To an observer any where between either pole and equator, the parallels described by the Sun and stars are cut obliquely by the horizon, and therefore he is said to have an *oblique* position of the sphere. To an observer any where on the equator the parallels of motion, described by the Sun and stars, are cut perpendicularly, or at right angles, by the horizon; and therefore he is said to have a *right* position of the sphere. And these three are all the different ways that the sphere can be posited to the inhabitants of the Earth. Fig. I. Parallel, oblique, and right spheres, what.

CHAP. V.

The Phenomena of the Heavens as seen from different Parts of the Solar System.

132. SO vastly great is the distance of the starry heavens, that if viewed from any part of the solar system, or even many millions of miles beyond it, the appearance would be the very same as it is to us. The Sun and stars would all seem to be fixed on one concave surface, of which the spectator's eye would be the centre. But the planets, being much nearer than the stars, their appearances will vary considerably with the place from which they are viewed.

133. If the spectator be at rest without the orbits of the planets, they will seem to be at the same distance as the stars; but continually changing their places with respect to the stars, and to one another; assuming various phases of increase and decrease like the Moon; and, notwithstanding their regular motions about the Sun, will sometimes appear to move quicker, sometimes slower, be as often to the west as to the east of the Sun, and at their greatest distances seem quite stationary. The duration, extent, and distance, of those points in the heavens where these digressions begin and end, would be more or less, according to the respective distances of the several planets from the Sun: but in the same planet, they would continue invariably the same at all times;—like pendulums of unequal lengths oscillating together, the shorter would move quick, and go over a small space; the longer would move slow, and go over a large space. If the observer be at rest within the orbits of the planets, but not near the common centre, their apparent motions will be irregular; but less so than in the former case. Each of the several planets will appear larger and less by turns, as they approach

nearer to, or recede farther from, the observer; the nearest varying most in their size. They will also move quicker or slower with regard to the fixed stars, but will never be either retrograde or stationary.

134. If an observer in motion view the heavens, the same apparent irregularities will be observed, but with some variation resulting from his own motion. If he be on a planet which has a rotation on its axis, not being sensible of his own motion, he will imagine the whole heavens, Sun, planets, and stars, to revolve about him in the same time that his planet turns round, but the contrary way; and will not be easily convinced of the deception. If his planet move round the Sun, the same irregularities and aspects as above mentioned will appear in the motions of the other planets; and the Sun will seem to move among the fixed stars or signs, in an opposite direction to that in which his planet moves, changing its place every day as he does. In a word, whether our observer be in motion or at rest, whether within or without the orbits of the planets, their motions will seem irregular, intricate, and perplexed, unless he be placed in the centre of the system; and from thence, the most beautiful order and harmony will be seen by him.

The Sun's centre the only point from which the true motions and places of the planets could be seen.

135. The Sun being the centre of all the planets' motions, the only place from which their motions could be truly seen, is the Sun's centre; where the observer being supposed not to turn round with the Sun (which, in this case, we must imagine to be a transparent body) would see all the stars at rest, and seemingly equidistant from him. To such an observer, the planets would appear to move among the fixed stars; in a simple, regular, and uniform manner: only, that as in equal times they describe equal areas, they would describe spaces somewhat unequal, because they move in elliptic orbits, § 155. Their motions would also appear to be what they are in fact, the same way round the heavens; in

paths which cross at small angles in different parts of the heavens, and then separate a little from one another, § 20. So that, if the solar astronomer should make the path or orbit of any planet a standard, and consider it as having no obliquity, § 201, he would judge the paths of all the rest to be inclined to it; each planet having one half of its path on one side, and the other half on the opposite side of the standard-path or orbit. And if he should ever see all the planets start from a conjunction with each other*, Mercury would move so much faster than Venus, as to overtake her again (though not in the same point of the heavens) in a space of time about equal to 145 of our days and nights, or, as we commonly call them, *natural days*, which include both the days and nights: Venus would move so much faster than the Earth, as to overtake it again in 585 natural days: the Earth so much faster than Mars, as to overtake him again in 778 such days: Mars so much faster than Jupiter, as to overtake him again in 817 such days: and Jupiter so much faster than Saturn, as to overtake him again in 7236 days, all of our time.

The judgment that a solar astronomer would probably make concerning the distances and magnitudes of the planets.

136. But as our solar astronomer could have no idea of measuring the courses of the planets by our days, he would probably take the period of Mercury, which is the quickest-moving planet, for a measure to compare the periods of the others with. As all the stars would appear quiescent to him, he would never think that they had any dependance upon the Sun; but would naturally imagine that the planets have, because they move round the Sun. And it is by no means improbable, that he

* Here we do not mean such a conjunction, as that the nearest planet should hide all the rest from the observer's sight; (for that would be impossible, unless the intersections of all their orbits were coincident, which they are not. *See* § 21.) but when they were all in a line crossing the standard-orbit at right angles.

would conclude those planets, whose periods are quickest, to move in orbits proportionably less than those do which make slower circuits. But being destitute of a method for finding their parallaxes, or, more properly speaking, as they would have no parallax to him, he could never know any thing of their real distances or magnitudes. Their relative distances he might perhaps guess at by their periods, and from thence infer something of truth concerning their relative magnitudes, by comparing their apparent magnitudes with one another. For example, Jupiter appearing larger to him than Mars, he would conclude it to be so in fact; and that it must be farther from him, on account of its longer period. Mercury and the Earth would appear to be nearly of the same magnitude; but by comparing the period of Mercury with that of the Earth, he would conclude that the Earth is much farther from him than Mercury, and consequently that it must be really larger though apparently of the same magnitude; and so of the rest. And as each planet would appear somewhat larger in one part of its orbit than in the opposite, and to move quickest when it seems largest, the observer would be at no loss to conclude that all the planets move in orbits, of which the Sun is not precisely the centre.

The planetary motions very irregular as seen from the Earth.

137. The apparent magnitudes of the planets continually change as seen from the Earth, which demonstrates that they approach nearer to it, and recede farther from it by turns. From these phenomena, and their apparent motions among the stars, they seem to describe looped curves, which never return into themselves,—Venus's path excepted. And if we were to trace out all their apparent paths, and put the figures of them together in one diagram, they would appear so anomalous and confused, that no man in his senses could believe them to be representations of their real paths; but would immediately conclude, that such appa-

Plate III. rent irregularities must be owing to some optic illusions. And after a good deal of enquiry, he might perhaps be at a loss to find out the true causes of these irregularities; especially if he were one of those who would rather, with the greatest justice, charge frail man with ignorance, than the Almighty with being the author of such confusion.

Those of Mercury and Venus represented.

138. Dr. LONG, in his first volume of *Astronomy*, has given us figures of the apparent paths of all the planets, separately from CASSINI; and on seeing them I first thought of attempting to trace some of them by a machine* that shews the motions of the Sun, Mercury, and Venus, the Earth, and Moon, according to the *Copernican System*. Having taken off the Sun, Mercury, and Venus, I put black-lead pencils in their places, with the points turned upward; and fixed a circular sheet of paste-board so, that the Earth kept constantly under its centre in going round the Sun; and the paste-board kept its parallelism. Then, pressing gently with one hand upon the paste-board, to make it touch the three pencils; with the other hand I turned the winch that moves the whole machinery: and as the Earth, together with the pencils in the places of Mercury and Venus, had their proper motions round the Sun's pencil, which kept at rest in the centre of the machine, all the three pencils described a diagram, from which the first figure of the third plate is truly copied in a smaller size. As the Earth moved round the Sun, the Sun's pencil described the dotted circle of months, whilst Mercury's pencil drew the curve with the greatest number of loops, and Venus's that with the fewest. In their inferior conjunctions they come as much nearer to the Earth, or within the circle of the Sun's apparent motion round the heavens, as they go beyond it in their superior conjunctions. On each side of the loops they appear stationary: in that part of

Fig. I.

* The ORRERY fronting the Title-Page.

each loop next the Earth, retrograde; and in all the rest of their paths, direct. *Plate III.*

If *Cassini's* figures of the paths of the Sun, Mercury, and Venus, were put together, the figure, as above traced out, would be exactly like them. It represents the Sun's apparent motion round the ecliptic, which is the same every year; Mercury's motion for seven years; and Venus's for eight; in which time Mercury's path makes 23 loops, crossing itself so many times, and Venus's only five. In eight years Venus falls so nearly into the same apparent path again, as to deviate very little from it in some ages; but in what number of years Mercury and the rest of the planets would describe the same visible paths over again, I cannot at present determine. Having finished the above figure of the paths of Mercury and Venus, I put the ecliptic round them as in the doctor's book; and added the dotted lines from the Earth to the ecliptic, for shewing Mercury's apparent or geocentric motion therein for one year; in which time his path makes three loops, and goes on a little farther.—This shews that he has three inferior, and as many superior conjunctions with the Sun in that time; and also that he is six times stationary, and thrice retrograde. Let us now trace his motion for one year in the figure.

Suppose Mercury to be setting out from *A* toward *B* (between the Earth and left-hand corner of the plate) and as seen from the Earth, his motion will then be direct, or according to the order of the signs. But when he comes to *B*, he appears to stand still in the 23d degree of ♏ at *F*, as shewn by the line *B F*. While he goes from *B* to *C*, the line *B F*, supposed to move with him, goes backward from *F* to *E*, or contrary to the order of signs: and when he is at *C*, he appears stationary at *E*; having gone back 11½ degrees. Now, suppose him stationary on the first of *January* at *C*, on the tenth of that month he will appear in the heavens *Fig. I.*

as at 20, near *F*; on the 20th he will be seen as at *G*; on the 31st at *H*; on the 10th of *February* at *F*; on the 20th at *K*; and on the 28th at *L*; as the dotted lines shew, which are drawn through every tenth days' motion in his looped path, and continued to the ecliptic. On the 10th of *March* he appears at *M*; on the 20th at *N*; and on the 31st at *O*. On the tenth of *April* he appears stationary at *P*; on the 20th he seems to have gone back again to *O*; and on the 30th he appears stationary at *Q*, having gone back 11½ degrees. Thus Mercury seems to go forward 4 signs 11 degrees, or 131 degrees; and to go back only 11 or 12 degrees, at a mean rate. From the 30th of *April* to the 10th of *May*, he seems to move from *Q* to *R*; and on the 20th he is seen at *S*, going forward in the same manner again, according to the order of letters; and backward when they go back; which it is needless to explain any farther, as the reader can trace him out so easily, through the rest of the year. The same appearances happen in Venus's motion; but as she moves slower than Mercury, there are longer intervals of time between them.

Having already, § 120, given some account of the apparent diurnal motions of the heavens as seen from the different planets, we shall not trouble the reader any more with that subject.

CHAP. VI.

The Ptolemean *System refuted. The Motions and Phases of Mercury and Venus explained.*

139. THE *Tychonic System*, § 97, being sufficiently refuted in the 109th article, we shall say nothing more about it.

140. The *Ptolemean System*, § 96, which asserts the Earth to be at rest in the centre of the universe, and all the planets with the Sun and stars to move round it, is evidently false and absurd.

For if this hypothesis were true, Mercury and Venus could never be hid behind the Sun, as their orbits are included within the Sun's; and again, these two planets would always move direct, and be as often in opposition to the Sun as in conjunction with him. But the contrary of all this is true: for they are just as often behind the Sun as before him, appear as often to move backward as forward, and are so far from being seen at any time in the side of the heavens opposite to the Sun, that they are never seen a quarter of a circle in the heavens distant from him.

Appearances of Mercury and Venus.

141. These two planets, when viewed at different times with a good telescope, appear in all the various shapes of the Moon; which is a plain proof that they are enlightened by the Sun, and shine not by any light of their own; for if they did, they would constantly appear round as the Sun does; and could never be seen like dark spots upon the Sun when they pass directly between him and us. Their regular phases demonstrate them to be spherical bodies; as may be shewn by the following experiment:

Experiment to prove they are round.

Hang an ivory ball by a thread, and let any person move it round the flame of a candle, at two or three yards distance from your eye; when the ball is beyond the candle, so as to be almost hid by the flame, its enlightened side will be toward you, and appear round like the full Moon: When the ball is between you and the candle, its enlightened side will disappear as the Moon does at the change: When it is half-way between these two positions, it will appear half illuminated, like the Moon in her quarters: but in every other place between these positions, it will appear more or less horned or gibbous. If this experiment be made with a flat circular plate, you may make it appear fully enlightened, or not enlightened at all; but can never make it appear either horned or gibbous.

Plate II.

Experiment to represent the motions of Mercury and Venus.

142. If you remove about six or seven yards from the candle, and place yourself so that its flame may be just about the height of your eye, and then desire the other person to move the ball slowly round the candle as before, keeping it as nearly of an equal height with the flame as he possibly can, the ball will appear to you not to move in a circle, but to vibrate backward and forward like a pendulum; moving quickest when it is directly between you and the candle, and when directly beyond it; and gradually slower as it goes farther to the right or left side of the flame, until it appears at the greatest distance from the flame; and then, though it continues to move with the same velocity, it will seem for a moment to stand still. In every revolution it will shew all the above phases, § 141; and if two balls, a smaller and a greater, be moved in this manner round the candle, the smaller ball being kept nearest the flame, and carried round almost three times as often as the greater, you will have a tolerable good representation of the apparent motions of Mercury and Venus; especially if the greater ball describe a circle almost twice as large in diameter as that described by the lesser.

Fig. III.

143. Let *A B C D E* be a part or segment of the visible heavens, in which the Sun, Moon, planets, and stars, appear to move at the same distance from the Earth *E*. For there are certain limits, beyond which the eye cannot judge of different distances; as is plain from the Moon's appearing to be as far from us as the Sun and stars are. Let the circle *f g h i k l m n o* be the orbit in which Mercury *m* moves round the Sun *S*, according to the order of the letters. When Mercury is at *f*, he disappears to the Earth at *E*, because his enlightened side is turned from it; unless he be then in one of his nodes, § 20, 25; in which case he will appear like a dark spot upon the Sun. When he is at *g* in his orbit, he appears at *B* in the heavens, west-

The elongations or digressions of Mercury from the Sun.

ward of the Sun *S*, which is seen at *C*: when at *h*, he appears at *A*, at his greatest western elongation or distance from the Sun; and then seems to stand still. But, as he moves from *h* to *i*, he appears to go from *A* to *B*; and seems to be in the same place when at *i*, as when he was at *g*, but not near so large: at *k* he is hid from the Earth *E*, by the Sun *S*; being then in his superior conjunction. In going from *k* to *l*, he appears to move from *C* to *D*; and when he is at *n*, he appears stationary at *E*; being seen as far east from the Sun then, as he was west from it at *A*. In going from *n* to *o*, in his orbit, he seems to go back again in the heavens, from *E* to *D*; and is seen in the same place (with respect to the Sun) at *o*, as when he was at *l*; but of a larger diameter at *o*, because he is then nearer the Earth *E*: and when he comes to *f*, he again passes by the Sun, and disappears as before. In going from *n* to *h*, in his orbit, he seems to go backward in the heavens from *E* to *A*; and in going from *h* to *n*, he seems to go forward from *A* to *E*: as he goes on from *f*, a little of his enlightened side at *g* is seen from *E*; at *h* he appears half full, because half of his enlightened side is seen; at *i*, gibbous, or more than half full; and at *k* he would appear quite full, were he not hid from the Earth *E* by the Sun *S*. At *l* he appears gibbous again, at *n* half decreased, at *o* horned, and at *f* new, like the Moon at her change. He goes sooner from his eastern station at *n* to his western station at *h*, than again from *h* to *n*; because he goes through less than half his orbit in the former case, and through more in the latter. *Plate II.*

144. In the same figure, let *FGHIKLMN* be the orbit in which Venus *v* goes round the Sun *S*, according to the order of the letters: and let *E* be the Earth, as before. When Venus is at *F*, she is in her inferior conjunction; and disappears like the new Moon, because her dark side is toward the Earth. At *G*, she appears half enlightened to the *Fig. III.* *The elongations and phases of Venus.*

Earth, like the moon in her first quarter: at *H*, she appears gibbous; at *I*, almost full; her enlightened side being then nearly towards the Earth; at *K*, she would appear quite full to the Earth *E*; but is hid from it by the Sun *S*; at *L*, she appears upon the decrease, or gibbous; at *M*, more so; at N, only half enlightened; and at *F*, she again disappears. In moving from *N* to *G*, she seems to go backward in the heavens; and from *G* to *N*, forward; but as she describes a much greater portion of her orbit in going from *G* to *N*, than from *N* to *G*, she appears much longer direct than retrograde in her motion. At *N* and *G* she appears stationary; as Mercury does at *n* and *h*. Mercury, when stationary, seems to be only 28 degrees from the Sun; and Venus, when so, 47; which is a demonstration that Mercury's orbit is included within Venus's, and Venus's within the Earth's.

The greatest elongations of Mercury and Venus.

145. Venus, from her superior conjunction at *K*, to her inferior conjunction at *F*, is seen on the east side of the Sun *S*, from the Earth *E*; and therefore she shines in the evening after the Sun sets, and is called *the evening star*; for, the Sun being then to the westward of Venus, must set first. From her inferior conjunction to her superior, she appears on the west side of the Sun; and therefore rises before him; for which reason she is called *the morning star*. When she is about *N* or *G*, she shines so bright, that bodies by her light cast shadows in the night-time.

Morning and evening star, what.

146. If the Earth kept always at *E*, it is evident that the stationary places of Mercury and Venus would always be in the same points of the heavens where they were before. For example: whilst Mercury *m* goes from *h* to *n*, according to the order of the letters, he appears to describe the arc *ABCDE* in the heavens, direct: and while he goes from *n* to *h*, he seems to describe the same arc back again, from *E* to *A*, retrograde; always at *n* and *h* he

The stationary places of the planets variable.

appears stationary at the same points E and A as before. But Mercury goes round his orbit, from f to f again, in 88 days; and yet there are 116 days from any one of his conjunctions, or apparent stations, to the same again: and the places of these conjunctions and stations are found to be about 114 degrees eastward from the points of the heavens where they were last before; which proves that the Earth has not kept all that time at E, but has had a progressive motion in its orbit from E to t. Venus also differs every time in the places of her conjunctions and stations; but much more than Mercury; because, as Venus describes a much larger orbit than Mercury does, the Earth advances so much the farther in its annual path, before Venus comes round again.

The elongations of all Saturn's inferior planets as seen from him.

147. As Mercury and Venus, seen from the Earth, have their respective elongations from the Sun, and stationary places; so has the Earth, seen from Mars; and Mars, seen from Jupiter; and Jupiter, seen from Saturn: that is, to every superior planet, all the inferior ones have their stations and elongations; as Venus and Mercury have to the Earth. As seen from Saturn, Mercury never goes more than $2\frac{1}{4}$ degrees from the Sun; Venus $4\frac{1}{3}$; the Earth 6; Mars $9\frac{1}{2}$; and Jupiter $33\frac{1}{4}$; so that Mercury, as seen from the Earth, has almost as great a digression or elongation from the Sun, as Jupiter, seen from Saturn.

A proof of the Earth's annual motion.

148. Because the Earth's orbit is included within the orbits of Mars, Jupiter, and Saturn, they are seen on all sides of the heavens: and are as often in opposition to the Sun as in conjunction with him. If the Earth stood still, they would always appear direct in their motions, never retrograde nor stationary. But they seem to go just as often backward as forward; which, if gravity be allowed to exist, affords a sufficient proof of the Earth's annual motion: and without its existence, the planets could never fall from the tangents of their orbits towards

Plate II. the Sun, nor could a stone, which is once thrown up from the Earth, ever fall to the earth again.

149. As Venus and the Earth are superior planets to Mercury, they exhibit much the same appearances to him, that Mars and Jupiter do to us. Let Mercury *m* be at *f*, Venus *v* at *F*, and the Earth at *E*; in which situation Venus hides the Earth from Mercury; but being in opposition to the Sun, she shines on Mercury with a full illumined orb; though, with respect to the Earth, she is in conjunction with the Sun, and invisible. When Mercury is at *f*, and Venus at *G*, her enlightened side not being directly toward him, she appears a little gibbous; as Mars does in a like situation to us: but, when Venus is at *I*, her enlightened side is so much toward Mercury at *f*, that she appears to him almost of a round figure. At *K*, Venus disappears to Mercury at *f*, being then hid by the Sun, as all our superior planets are to us, when in conjunction with the Sun. When Venus has, as it were, emerged out of the Sun-beams, as at *L*, she appears almost full to Mercury at *f*; at *M* and *N*, a little gibbous; quite full at *F*, and largest of all; being then in opposition to the Sun, and consequently nearest to Mercury at *F*; shining strongly on him in the night, because her distance from him then is somewhat less than a fifth part of her distance from the Earth, when she appears roundest to it between *I* and *K*, or between *K* and *L*, as seen from the Earth *E*. Consequently, when Venus is opposite to the Sun as seen from Mercury, she appears more than 25 times as large to him as she does to us when at the fullest. Our case is almost similar with respect to Mars, when he is opposite to the Sun; because he is then so near the Earth, and has his whole enlightened side toward it. But, because the orbits of Jupiter and Saturn are very large in proportion to the Earth's orbit, these two planets appear much less magnified

Fig. III. General phenomena of a superior planet to an inferior.

at their oppositions, or diminished at their conjunctions, than Mars does, in proportion to their mean apparent diameters. *Plate II.*

CHAP. VII.

The Physical Causes of the Motions of the Planets. The Eccentricities of their Orbits. The Times in which the Action of Gravity would bring them to the Sun. ARCHIMEDES's *ideal Problem for moving the Earth. The World not eternal.*

150. FROM the uniform projectile motion of bodies in straight lines, and the universal power of attraction which draws them off from these lines, the curvilineal motions of all the planets arise. If the body *A* be projected along the right line *ABX*, in open space, where it meets with no resistance, and is not drawn aside by any other power, it would for ever go on with the same velocity, and in the same direction. For, the force which moves it from *A* to *B* in any given time, will carry it from *B* to *X* in as much more time, and so on, there being nothing to obstruct or alter its motion. But if, when this projectile force has carried it, suppose to *B*, the body *S* begin to attract it, with a power duly adjusted, and perpendicular to its motion at *B*, it will then be drawn from the straight line *ABX*, and forced to revolve about *S* in the circle *BYTU*. When the body *A* comes to *U*, or any other part of its orbit, if the small body *u*, within the sphere of *U*'s attraction, be projected, as in the right line *Z*, with a force perpendicular to the attraction of *U*, then *u* will go round *U* in the orbit *W*, and accompany it in its whole course round the body *S*. Here *S* may represent the Sun, *U* the Earth, and *u* the Moon.

Gravitation and projection. Fig. IV. Circular orbits. Fig. IV.

151. If a planet at *B* gravitate, or be attracted, toward the Sun, so as to fall from *B* to *y* in the

time that the projectile force would have carried it from B to X, it will describe the curve $B\ Y$ by the combined action of these two forces, in the same time that the projectile force singly would have carried it from B to X, or the gravitating power singly have caused it to descend from B to y; and these two forces being duly proportioned, and perpendicular to each other, the planet, obeying them both, will move in the circle $BYTU$*.

152. But if, while the projectile force would carry the planet from B to b, the Sun's attraction (which constitutes the planet's gravitation) should bring it down from B to 1, the gravitating power would then be too strong for the projectile force; and would cause the planet to describe the curve $B\ C$. When the planet comes to C, the gravitating power (which always increases as the square of the distance from the Sun S diminishes) will be yet stronger on account of the projectile force; and by conspiring in some degree therewith, will accelerate the planet's motion all the way from C to K; causing it to describe the arcs BC, CD, DE, EF, &c. all in equal times. Having its motion thus accelerated, it thereby gains so much centrifugal force or tendency to fly off at K in the line Kk, as overcomes the Sun's attraction: and the centrifugal force being too great to allow the planet to be brought nearer the Sun, or even to move round him in the circle $Klmn$, &c. it goes off, and ascends in the curve $KLMN$, &c. its motion decreasing as gradually from K to B, as it increases from B to K; because the Sun's attraction now acts against the planet's projectile motion just as much as it acted with it before. When the planet has got round to B, its projectile force is as much diminished from its mean state about G or N,

Elliptical orbits.

* To make the projectile force balance the gravitating power so exactly as that the body may move in a circle, the projectile velocity of the body must be such as it would have acquired by gravity alone, in falling through half the radius of the circle.

as it was augmented at *K*; and so, the Sun's attraction being more than sufficient to keep the planet from going off at *B*, it describes the same orbit over again, by virtue of the same forces or powers. *Plate II.*

153. A double projectile force will always balance a quadruple power of gravity. Let the planet at *B* have twice as great an impulse from thence toward *X*, as it had before; that is, in the same length of time that it was projected from *B* to *b*, as in the last example, let it now be projected from *B* to *c*; and it will require four times as much gravity to retain it in its orbit: that is, it must fall as far as from *B* to 4 in the time that the projectile force would carry it from *B* to *c*; otherwise it could not describe the curve *BD*; as is evident by the figure. But, in as much time as the planet moves from *B* to *C* in the higher part of its orbit, it moves from *I* to *K*, or from *K* to *L*, in the lower part thereof; because, from the joint action of these two forces, it must always describe equal areas in equal times, throughout its annual course. These areas are represented by the triangles *BSC*, *CSD*, *DSE*, *ESF*, &c. whose contents are equal to one another quite round the figure. Fig. IV. The planets describe equal areas in equal times.

154. As the planets approach nearer the Sun, and recede farther from him, in every revolution; there may be some difficulty in conceiving the reason why the power of gravity, when it once gets the better of the projectile force, does not bring the planets nearer and nearer the Sun in every revolution, till they fall upon, and unite with him; or why the projectile force, when it once gets the better of gravity, does not carry the planets farther and farther from the Sun, till it removes them quite out of the sphere of his attraction, and causes them to go on in straight lines for ever afterward. But by considering the effects of these powers as described in the two last articles, this difficulty will be removed. Suppose a planet A difficulty removed.

at *B*, to be carried by the projectile force as far as from *B* to *b*, in the time that gravity would have brought it down from *B* to 1: by these two forces it will describe the curve *B C*. When the planet comes down to *K*, it will be but half as far from the Sun *S* as it was at *B*; and therefore by gravitating four times as strongly towards him, it would fall from *K* to *V* in the same length of time that it would have fallen from *B* to 1 in the higher part of its orbit; that is through four times as much space; but its projectile force is then so much increased at *K*, as would carry it from *K* to *k* in the same time; being double of what it was at *B*; and is therefore too strong for the gravitating power, either to draw the planet to the Sun, or cause it to go round him in the circle *Klmn*, &c. which would require its falling from *K* to *w*, through a greater space than that through which gravity can draw it, while the projectile force is such as would carry it from *K* to *k*: and therefore the planet ascends in its orbit *KLMN*, decreasing in its velocity, for the causes already assigned in § 152.

The planetary orbits elliptical.

155. The orbits of all the planets are ellipses, very little different from circles: but the orbits of the comets are very long ellipses; and the lower focus of them all is in the Sun. If we suppose the mean distance (or middle between the greatest and least) of every planet and comet from the Sun to be divided into 1000 equal parts, the eccentricities of their orbits, both in such parts and in *English* miles, will be as follow: Mercury's, 210 parts, or 6,720,000 miles; Venus's, 7 parts, or 413,000 miles; the Earth's, 17 parts, or 1,377,000 miles; Mars's, 93 parts, or 11,439,000 miles; Jupiter's, 48 parts, or 20,352,000 miles; Saturn's, 55 parts, or 42,735,000 miles. Of the nearest of the tree forementioned comets, 1,458,000 miles; of the middlemost, 2,025,000,000 miles; and of the outermost, 6,600,000,000.

Their eccentricities.

156. By the above-mentioned law, § 150 & *seq.* bodies will move in all kinds of ellipses, whether long or short, if the spaces they move in be void of resistance. Only those which move in the longer ellipses have so much the less projectile force impressed upon them in the higher parts of their orbits; and their velocities, in coming down towards the Sun, are so prodigiously increased by his attraction, that their centrifugal forces in the lower parts of their orbits are so great, as to overcome the Sun's attraction there, and cause them to ascend again towards the higher parts of their orbit; during which time the Sun's attraction, acting so contrary to the motions of those bodies, causes them to move slower and slower, until their projectile forces are diminished almost to nothing; and then they are brought back again by the Sun's attraction as before.

The above laws sufficient for motions both in circular and elliptic orbits.

157. If the projectile forces of all the planets and comets were destroyed at their mean distances from the Sun, their gravities would bring them down so, as that Mercury would fall to the Sun in 15 days 13 hours; Venus, in 39 days 17 hours; the Earth or Moon, in 64 days 10 hours; Mars, in 121 days; Jupiter, in 290; and Saturn, in 767. The nearest comet, in 13 thousand days; the middlemost, in 23 thousand days; and the outermost, in 66 thousand days. The Moon would fall to the Earth in 4 days 20 hours; Jupiter's first moon would fall to him in 7 hours, his second in 15, his third in 30, and his fourth in 71 hours. Saturn's first moon would fall to him in 8 hours, his second in 12, his third in 19, his fourth in 68, and his fifth in 336 hours. A stone would fall to the Earth's centre, if there were a hollow passage, in 21 minutes 9 seconds. Mr. WHISTON gives the following *rule* for such computations. "*It is demonstrable, that half the period of any planet, when it is diminished in the sesquialteral proportion

In what times the planets would fall to the Sun by the power of gravity.

* Astronomical Principles of Religion, p. 66.

of the number 1 to the number 2, or nearly in the proportion of 1000 to 2828, is the time in which it would fall to the centre of its orbit.

The prodigious attraction of the Sun and Planets.

158. The quick motions of the moons of Jupiter and Saturn round their primaries, demonstrate that these two planets have stronger attractive powers than the Earth has. For the stronger that one body attracts another, the greater must be the projectile force, and consequently the quicker must be the motion of that other body to keep it from falling to its primary or central planet. Jupiter's second moon is 124 thousand miles farther from Jupiter than our Moon is from us; and yet this second moon goes almost eight times round Jupiter whilst our moon goes only once round the Earth. What a prodigious attractive power must the Sun then have, to draw all the planets and satellites of the system towards him! and what an amazing power must it have required to put all these planets and moons into such rapid motions at first! Amazing indeed to us, because impossible to be effected by the strength of all the living creatures in an unlimited number of worlds; but no ways hard for the Almighty, whose planetarium takes in the whole universe.

ARCHIMEDES's problem for raising the Earth.

159. The celebrated ARCHIMEDES affirmed he could move the Earth, if he had a place at a distance from it to stand upon to manage his machinery.*. This assertion is true in theory, but, upon examination, will be found absolutely impossible in fact, even though a proper place, and materials of sufficient strength could be had.

The simplest and easiest method of moving a heavy body a little way, is by a lever or crow; where a small weight or power applied to the long arm will raise a great weight on the short one. But then the small weight must move as much quicker than the great weight, as the latter is heavier than

* Δος πῦ σῶ, και τον κοσμον κινήσω, i. e. Give me a place to stand on, and I shall move the Earth.

the former; and the length of the long arm of the lever must be in the same proportion to the length of the short one. Now, suppose a man to pull, or press the end of the long arm with the force of 200 pounds weight, and that the Earth contains in round numbers, 4,000,000,000,000,000,000,000, or 4000 trilions of cubit feet, each at a mean rate weighing 100 pound; and that the prop or centre of motion of the lever is 6000 miles from the Earth's centre: in this case, the length of the lever from the *fulcrum* or centre of motion to the moving power or weight ought to be 12,000,000,000,000,000,000,000, 000, or 12 quadrillions of miles; and so many miles must the power move, in order to raise the Earth but one mile; whence it is easy to compute, that if ARCHIMEDES, or the power applied, could move as swift as a cannon bullet, it would take 27,000,000,000, 000, or 27 billions of years to raise the Earth one inch.

If any other machine, such as a combination of wheels and screws, were proposed to move the Earth, the time it would require, and the space gone through by the hand that turned the machine, would be the same as before. Hence we may learn, that however boundless our imagination and theory may be, the actual operations of man are confined within narrow bounds; and more suited to our real wants than to our desires.

160. The Sun and planets mutually attract each other: the power by which they do so we call *gravity*. But whether this power be mechanical or not, is very much disputed. Observation proves that by it the planets disturb one another's motions, and that it decreases, according to the squares of the distances of the Sun and planets inversely; as light, which is known to be material, likewise does. Hence, gravity should seem to arise from the agency of some subtle matter pressing toward the Sun and planets, and acting, like all mechanical causes, by contact. Hard to determine what gravity is

But, on the other hand, when we consider that the degree or force of gravity is exactly in proportion to the quantities of matter in those bodies, without any regard to their bulk or quantity of surface, acting as freely on their internal as external parts, it seems to surpass the power of mechanism, and to be either the immediate agency of the Deity, or effected by a law originally established and imprest on all matter by him. But some affirm that matter, being altogether inert, cannot be impressed with any law, even by Almighty power: and that the Deity, or some subordinate intelligence, must therefore be constantly impelling the planets towards the Sun, and moving them with the same irregularities and disturbances which gravity would cause, if it could be supposed to exist. But, if a man may venture to publish his own thoughts, it seems to me no more an absurdity, to suppose the Deity capable of infusing a law, or what law he pleases, into matter, than to suppose him capable of giving it existence at first. The manner of both is equally inconceivable to us; but neither of them imply a contradiction in our ideas: and what implies no contradiction is within the power of Omnipotence.

161. That the projectile force was at first given by the Deity is evident. For matter can never put itself in motion, and all bodies may be moved in any direction whatever; and yet the planets, both primary and secondary, move from west to east, in planes nearly coincident; while the comets move in all directions, and in planes very different from one another; these motions can therefore be owing to no mechanical cause or necessity, but to the free will and power of an intelligent Being.

162. Whatever gravity be, it is plain that it acts every moment of time: for if its action should cease, the projectile force would instantly carry off the

planets in straight lines from those parts of their orbits where gravity left them. But, the planets being once put into motion, there is no occasion for any new projectile force, unless they meet with some resistance in their orbits; nor for any mending hand, unless they disturb one another too much by their mutual attractions.

163. It is found that there are disturbances among the planets in their motions, arising from their mutual attractions, when they are in the same quarter of the heavens; and the best modern observers find that our years are not always precisely of the same length*. Besides, there is reason to believe that the Moon is somewhat nearer the Earth now than she was formerly; her periodical month being shorter than it was in former ages. For our astronomical tables, which in the present age shew the times of solar and lunar eclipses to great precision, do not answer so well for very ancient eclipses. Hence it appears, that the Moon does not move in a medium void of all resistance, § 174: and therefore her projectile force being a little weakened, while there is nothing to diminish her gravity, she must be gradually approaching nearer the Earth, describing smaller and smaller circles round it in every revolution, and finishing her period sooner, although her absolute motion with regard to space be not so quick now as it was formerly: and, therefore, she must come to the Earth at last; unless that Being, which gave her a suffic ent projectile

The planets disturb one another's motions.

The consequences thereof.

* If the planets did not mutually attract one another, the areas described by them would be exactly proportionate to the times of description, § 153. But observations prove that these areas are not in such exact proportion, and are most varied when the greatest number of planets are in any particular quarter of the heavens. When any two planets are in conjunction, their mutual attractions, which tend to bring them nearer to one another, draw the inferior one a little farther from the Sun, and the superior one a little nearer to him; by which means, the figure of their orbits is somewhat altered: but this alteration is too small to be discovered in several ages.

jectile force at the beginning, adds a little more to it in due time. And, as all the planets move in spaces full of ether and light, which are material substances, they too must meet with some resistance. And, therefore, if their gravities be not diminished, nor their projectile forces increased, they must necessarily approach nearer and nearer the Sun, and at length fall upon and unite with him.

The world not eternal.

164. Here we have a strong philosophical argument against the eternity of the World. For, had it existed from eternity, and been left by the Deity to be governed by the combined actions of the above forces or powers, generally called laws, it had been at an end long ago. And if it be left to them, it must come to an end. But we may be certain, that it will last as long as was intended by its Author, who ought no more to be found fault with for framing so perishable a work, than for making man mortal*.

CHAP. VIII.

Of Light. Its proportional Quantities on the different Planets. Its Refractions in Water and Air. The Atmosphere; its Weight and Properties. The Horizontal moon.

The amazing smallness of the particles of light.

165. LIGHT consists of exceeding small particles of matter issuing from a luminous body; as, from a lighted candle such particles of matter constantly flow in all directions. Dr. NIEWENTYT† computes, that in one second of time there flow 418,660,000,000,000,000,000,000,000,000, 000,000,000,000,000, particles of light out of a burning candle; which number contains at least

* M. de la Grange has demonstrated, on the soundest principles of philosophy, that the solar system is not *necessarily* perishable; but that the seeming irregularities in the planetary motions osculate, as it were, within narrow limits; and that the *world*, according to the present constitution of nature, *may* be permanent.

† Religious Philosopher. Vol. III. p. 65.

6,337,242,000,000 times the number of grains of sand in the whole Earth; supposing 100 grains of sand to be equal in length to an inch, and consequently, every cubit inch of the Earth to contain one million of such grains.

166. These amazingly small particles, by striking upon our eyes, excite in our minds the idea of light; and if they were as large as the smallest particles of matter discernible by our best microscopes, instead of being serviceable to us, they would soon deprive us of sight, by the force arising from their immense velocity; which is above 164 thousand miles every second*, or 1,230,000 times swifter than the motion of a cannon bullet. And, therefore, if the particles of light were so large, that a million of them were equal in bulk to an ordinary grain of sand, we durst no more open our eyes to the light, than suffer sand to be shot point blank against them.

The dreadful effects that would ensue from their being larger.

167. When these small particles, flowing from the Sun or from a candle, fall upon bodies, and are thereby reflected to our eyes, they excite in us the idea of that body, by forming its picture on the retina †. And since bodies are visible on all sides, light must be reflected from them in all directions.

How objects become visible to us.

168. A ray of light is a continued stream of these particles, flowing from any visible body in a straight line. That the rays move in straight, and not in crooked lines, unless they be refracted, is evident from bodies not being visible if we endeavour to look at them through the bore of a bended pipe; and from their ceasing to be seen on the interposition of other bodies, as the fixed stars by the interposition of the Moon and planets, and the Sun wholly or in part by the interposition of the Moon, Mercury, or Venus. And that these rays do not interfere, or jostle one

The rays of light naturally move in straight lines.

A proof that they hinder not one another's motions

* This will be demonstrated in the eleventh chapter.
† A fine net-work membrane in the bottom of the eye

Plate II. another out of their ways, in flowing from different bodies all around, is plain from the following experiment. Make a little hole in a thin plate of metal, and set the plate upright on a table, facing a row of lighted candles standing by one another; then place a sheet of paper or pasteboard at a little distance from the other side of the plate, and the rays of all the candles, flowing through the hole, will form as many specks of light on the paper as there are candles before the plate; each speck as distinct and large, as if there were only one candle to cast one speck; which shews that the rays are no hindrance to each other in their motions, although they all cross in the hole.

169. Light, and therefore heat, so far as it depends on the Sun's rays, (§ 85, toward the end,) decreases in the inverse proportion of the squares of the distances of the planets from the Sun. This is easily demonstrated by a figure; which, together with its description, I have taken from Dr. SMITH's Optics*. Let the light which flows from a point *A*, and passes through a square hole *B*, be received upon a plane *C*, parallel to the plane of the hole; or, if you please, let the figure *C* be the shadow of the plane *B*; and when the distance *C* is double of *B*, the length and breadth of the shadow *C* will be each double of the length and breadth of the plane *B*; and treble when *AD* is treble of *AB*; and so on: which may be easily examined by the light of a candle placed at *A*. Therefore the surface of the shadow *C*, at the distance *AC* double of *AB*, is divisible into four squares, and at a treble distance, into nine squares, severally equal to the square *B*, as represented in the figure. The light, then, which falls upon the plane *B*, being suffered to pass to double that distance, will be uniformly spread over four times the space, and consequently will be four times

Fig. XI.

In what proportion light and heat decrease at any given distance from the Sun.

* Book I. Art. 57.

thinner in every part of that space; at a treble distance, it will be nine times thinner; and at a quadruple distance, sixteen times thinner, than it was at first; and so on, according to the increase of the square surfaces *B*, *C*, *D*, *E*, described upon the distances *AB*, *AC*, *AD*, *AE*. Consequently, the quantities of this rarefied light received upon a surface of any given size and shape whatever, removed successively to these several distances, will be but one-fourth, one-ninth, one-sixteenth, respectively, of the whole quantity received by it at the first distance *AB*. Or, in general words, the densities and quantities of light, received upon any given plane, are diminished in the same proportion, as the squares of the distances of that plane, from the luminous body, are increased: and on the contrary, are increased in the same proportion as these squares are diminished. *Plate II.*

170. The more a telescope magnifies the discs of the Moon and planets, so much the dimmer they appear than to the bare eye; because the telescope cannot magnify the quantity of light as it does the surface; and, by spreading the same quantity of light over a surface so much larger than the naked eye beheld, just so much dimmer must it appear when viewed by a telescope, than by the bare eye. Why the planets appear dimmer when viewed through telescopes than by the bare eye.

171. When a ray of light passes out of one medium* into another, it is refracted, or turned out of its first course, more or less, as it falls more or less obliquely on the refracting surface which divides the two mediums. This may be proved by several experiments; of which we shall only give three for example's sake. 1. In a bason, *FGH*, put a piece of money, as *DB*, and then retire from it to *A*; that is, till the edge of the bason at *E* just hides the money from your sight; then keeping your head Fig VIII.

* A medium, in this sense, is any transparent body, or that through which the rays of light can pass; as water, glass, diamond, air; and even a vacuum is sometimes called a medium.

steady, let another person fill the bason gently with water. As he fills it, you will see more and more of the piece *DB*; which will be all in view when the bason is full, and appear as if lifted up to *C*. For the ray *AEB*, which was straight while the bason was empty, is now bent at the surface of the water in *E*, and turned out of its rectilineal course into the direction *ED*. Or, in other words, the ray *DEK*, that proceeded in a straight line from the edge *D* while the bason was empty, and went above the eye at *A*, is now bent at *E*; and instead of going on in the rectilineal direction *DEK*, goes in the angled direction *DEA*, and by entering the eye at *A* renders the object *DB* visible. Or, 2dly, Place the bason where the Sun shines obliquely, and observe where the shadow of the rim *E* falls on the bottom, as at *B*: then fill it with water, and the shadow will fall at *D*; which proves that the rays of light, falling obliquely on the surface of the water, are refracted, or bent downward into it.

Refraction of the rays of light.

172. The less obliquely the rays of light fall upon the surface of any medium, the less they are refracted; and if they fall perpendicularly on it, they are not refracted at all. For, in the last experiment, the higher the Sun rises, the less will be the difference between the places where the edge of the shadow falls in the empty and in the full bason. And, 3dly, if a stick be laid over the bason, and the Sun's rays be reflected perpendicularly into it from a looking-glass, the shadow of the stick will fall upon the same place of the bottom, whether the bason be full or empty.

173. The denser that any medium is, the more is light refracted in passing through it.

The atmosphere.

174. The Earth is surrounded by a thin fluid mass of matter, called the *air* or *atmosphere*, which gravitates to the Earth, revolves with it in its diurnal motion, and goes round the Sun with it every year.

This fluid is of an elastic or springy nature, and its lowest part, being pressed by the weight of all the air above it, is pressed the closest together; and therefore the atmosphere is densest of all at the Earth's surface, and higher up becomes gradually rarer. "It is well known* that the air near the surface of our Earth possesses a space about 1200 times greater than water of the same weight. And therefore, a cylindric column of air 1200 feet high, is of equal weight with a cylinder of water of the same breadth, and but one foot high. But a cylinder of air reaching to the top of the atmosphere is of equal weight with a cylinder of water about 33 feet high†; and therefore, if from the whole cylinder of air, the lower part of 1200 feet high be taken away, the remaining upper part will be of equal weight with a cylinder of water 32 feet, high; wherefore, at the height of 1200 feet or two furlongs, the weight of the incumbent air is less, and consequently the rarity of the compressed air is greater, than near the Earth's surface, in the ratio of 33 to 32. And the air, at all heights whatever, supposing the expansion thereof to be reciprocally proportional to its compression (and this proportion has been proved by the experiments of Dr. *Hooke* and others) will be set down in the following table: in the first column of which you have the height of the air in miles, whereof 4000 make a semi-diameter of the Earth; in the second the compression of the air, or the incumbent weight; in the third its rarity or expansion, supposing gravity to decrease in the duplicate ratio of the distances from the Earth's centre: The small numeral figures being here used to shew what number of ciphers

* NEWTON'S *system of the World*, p. 120.
† This is evident from common pumps.

must be joined to the numbers expressed by the larger figures, as $0.^{17}1224$ for 0.0000000000000000 00 1224, and 26956^{15} for 26956000000000000000.

The air's compression and rarity at different heights.

AIR'S		
Height.	Compression.	Expansion.
0	33	. . 1
5	17.8515 . .	. . 1.8486
10	9.6717 . .	. . 3.4151
20	2.852 . . .	. . 11.571
40	0.2525 .	. 136.83
400	$0.^{17}1224.$	26956^{15}
4000	$0.^{105}4465$	73907^{102}
40000	$0.^{192}1628$	26263^{189}
400000	$0.^{210}7895$	41798^{207}
4000000	$0.^{212}9878$	33414^{209}
Infinite.	$0.^{212}9941$	54622^{209}

From the above table it appears that the air in proceeding upward is rarified in such manner, that a sphere of that air which is nearest the Earth but of one inch diameter, if dilated to an equal rarefaction with that of the air at the height of ten semi-diameters of the Earth, would fill up more space than is contained in the whole heavens on this side the fixed stars. And it likewise appears that the Moon does not move in a perfectly free and unresisting medium; although the air, at a height equal to her distances, is at least 3400^{100} times thinner than at the Earth's surface; and therefore cannot resist her motion, so as to be sensible, in many ages.

Its weight how found.

175. The weight of the air, at the Earth's surface, is found by experiments made with the air-pump; and also by the quantity of mercury that the atmosphere balances in the barometer; in which, at a mean state, the mercury stands 29½ inches high. And if the tube were a square inch wide, it would at that height contain 29½ cubic inches of mercury, which

is just 15 pounds weight; and so much weight of air every square inch of the Earth's surface sustains; and consequently every square foot 144 times as much. Now, as the Earth's surface contains, in round numbers, 200,000,000 square miles, it must contain no less than 5,575,680,000,000,000 square feet; which being multiplied by 2160, the number of pounds on each square foot, amounts to 12,043, 468,800,000,000,000 pounds, for the weight of the whole atmosphere. At this rate, a middle-sized man, whose surface is about 15 square feet, is pressed by 32,400 pounds weight of air all around; for fluids press equally up and down, and on all sides. But, because this enormous weight is equal on all sides, and counterbalanced by the spring of the air diffused through all parts of our bodies, it is not in the least degree felt by us.

176. Oftentimes the state of the air is such, that we feel ourselves languid and dull; which is commonly thought to be occasioned by the air's being foggy and heavy about us. But that the air is then too light, is evident from the mercury's sinking in the barometer, at which time it is generally found that the air has not sufficient strength to bear up the vapours which compose the clouds, for when it is otherwise, the clouds mount high, and the air is more elastic and weighty above us, by which means it balances the internal spring of the air within us, braces up our blood-vessels and nerves, and makes us brisk and lively.

A common mistake about the weight of the air

177. According to * Dr. KEILL, and other astronomical writers, it is entirely owing to the atmosphere that the heavens appear bright in the day-time. For, without an atmosphere, only that part of the heavens would shine in which the Sun was placed: and if we could live without air, and should turn our backs toward the Sun, the whole heavens

Without an atmosphere the heavens would always appear dark, and we should have no twilight.

* See his Astronomy, p. 232.

Plate II. would appear as dark as in the night, and the stars would be seen as clear as in the nocturnal sky. In this case, we should have no twilight; but a sudden transition from the brightest sun-shine to the blackest darkness, immediately after sun-set; and from the blackest darkness to the brightest sun-shine, at sun-rising; which would be extremely inconvenient, if not blinding, to all mortals. But, by means of the atmosphere, we enjoy the Sun's light, reflected from the aerial particles, for some time before he rises, and after he sets. For, when the Earth by its rotation has withdrawn our sight from the Sun, the atmosphere being still higher than we, has the Sun's light imparted to it; which gradually decreases until he has got 18 degrees below the horizon; and then, all that part of the atmosphere which is above us is dark. From the length of twilight, the Doctor has calculated the height of the atmosphere (so far as it is dense enough to reflect any light) to be about 44 miles. But it is seldom dense enough at the height of two miles to bear up the clouds.

It brings the Sun in view before he rises, and keeps him in view after he sets.

178. The atmosphere refracts the Sun's rays so, as to bring him in sight every clear day, before he rises in the horizon; and to keep him in view for some minutes after he is really set below it. For, at some times of the year, we see the Sun ten minutes longer above the horizon than he would be if there were no refraction; and above six minutes every day at a mean rate.

Fig. IX. 179. To illustrate this, let *IEK* be a part of the Earth's surface, covered with the atmosphere *HGFC*; and let *HEO* be the sensible horizon* of an observer at *E*. When the Sun is at *A*, really below the horizon, a ray of light, *AC*, proceeding from him comes straight to *C*, where it falls on the surface of the atmosphere, and there entering a denser medium, it is turned out of its rectilineal

* As far as one can see round him on the Earth.

course *ACdG*, and bent down to the observer's eye at *E*; who then sees the Sun in the direction of the refracted ray *Ede*, which lies above the horizon, and being extended out to the heavens, shews the Sun at *B*, § 171.

180. The higher the Sun rises, the less his rays are refracted, because they fall less obliquely on the surface of the atmosphere, § 172. Thus, when the Sun is in the direction of the line *EfL* continued, he is so nearly perpendicular to the surface of the Earth at *E*, that his rays are but very little bent from a rectilineal course.

181. The Sun is about 32¼ min. of a deg. in breadth, when at his mean distance from the Earth; and the horizontal refraction of his rays is 33¾ min. which being more than his whole diameter, brings all his disc in view, when his uppermost edge rises in the horizon. At ten deg. height, the refraction is not quite 5 min.; at 20 deg. only 2 min. 26 sec.; at 30 deg. but 1 min. 32 sec.; and at the zenith, it is nothing: the quantity throughout, is shewn by the following table, calculated by Sir ISAAC NEWTON.

The quantity of refraction.

182. *A* TABLE *shewing the Refractions of the Sun, Moon, and Stars; adapted to their apparent Altitudes.*

Appar. Alt.		Refrac- tion.		Ap Alt	Refrac- tion.		Ap. Alt.	Refrac- tion.	
D.	M.	M.	S.	D.	M.	S.	D.	M.	S.
0	0	33	45	21	2	18	56	0	36
0	15	30	24	22	2	11	57	0	35
0	30	27	35	23	2	5	58	0	34
0	45	25	11	24	1	59	59	0	32
1	0	23	7	25	1	54	60	0	31
1	15	21	20	26	1	49	61	0	30
1	30	19	46	27	1	44	62	0	28
1	45	18	22	28	1	40	63	0	27
2	0	17	8	29	1	36	64	0	26
2	30	15	2	30	1	32	65	0	25
3	0	13	20	31	1	28	66	0	24
3	30	11	57	32	1	25	67	0	23
4	0	10	48	33	1	22	68	0	22
4	30	9	50	34	1	19	69	0	21
5	0	9	2	35	1	16	70	0	20
5	30	8	21	36	1	13	71	0	19
6	0	7	45	37	1	11	72	0	18
6	30	7	14	38	1	8	73	0	17
7	0	6	47	39	1	6	74	0	16
7	30	6	22	40	1	4	75	0	15
8	0	6	0	41	1	2	76	0	14
8	30	5	40	42	1	0	77	0	13
9	0	5	22	43	0	58	78	0	12
9	30	5	6	44	0	56	79	0	11
10	0	4	52	45	0	54	80	0	10
11	0	4	27	46	0	52	81	0	9
12	0	4	5	47	0	50	82	0	8
13	0	3	47	48	0	48	83	0	7
14	0	3	31	49	0	47	84	0	6
15	0	3	17	50	0	45	85	0	5
16	0	3	4	51	0	44	86	0	4
17	0	2	53	52	0	42	87	0	3
18	0	2	43	53	0	40	88	0	2
19	0	2	34	54	0	39	89	0	1
20	0	2	26	55	0	38	90	0	0

183. In all observations, to obtain the true altitude of the Sun, Moon, or stars, the refraction must be subtracted from the observed altitude. But the quantity of refraction is not always the same at the same altitude; because heat diminishes the air's refractive power and density, and cold increases both; and therefore no one table can serve precisely for the same place at all seasons, nor even at all times of the same day, much less for different climates; it having been observed that the horizontal refractions are near a third part less at the equator than at *Paris*. This is mentioned by Dr. SMITH in the 370th remark on his Optics, where the following account is given of an extraordinary refraction of the Sun beams by cold. "There is a famous observation of this kind made by some *Hollanders* that wintered in *Nova-Zembla* in the year 1596, who were surprised to find, that after a continual night of three months, the Sun began to rise seventeen days sooner than according to computation, deduced from the altitude of the pole, observed to be 76°; which cannot otherwise be accounted for, than by an extraordinary refraction of the Sun's rays passing through the cold dense air in that climate. Kepler computes that the Sun was almost five degrees below the horizon when he first appeared; and consequently the refraction of his rays was about nine times greater than it is with us."

Plate II.

The inconstancy of refractions.

A very remarkable case concerning refractions.

184. The Sun and Moon appear of an oval figure, as *FCGD*, just after their rising, and before their setting: the reason of which is,—the refraction being greater in the horizon than at any distance above it, the lower limb *G* is more elevated by it than the upper. But although the refraction shortens the vertical diameter *FG*, it has no sensible effect on the horizontal diameter *CD*, which is all equally elevated. When the refraction is so small as to be im-

Fig. X

perceptible, the Sun and Moon appear perfectly round, as *A E B F.*

Our imagination cannot judge rightly of the distance of inaccessible objects ;

185. When we have nothing but our imagination to assist us in estimating distances, we are liable to be deceived; for bright objects seem nearer to us than those which are less bright, or than the same objects do when they appear less bright and worse defined, even though their distance be the same. And if in both cases they are seen under the same angle*, our imagination naturally suggests an idea of a greater distance between us and those objects which appear fainter and worse defined than those which appear brighter under the same angles; especially if they be such objects as we were never near to, and of whose real magnitudes we can be no judges by sight.

nor always of those which are accessible.

186. But it is not only in judging of the different apparent magnitudes of the same objects, which are better or worse defined by their being more or less bright, that we may be deceived: for we may make a wrong conclusion even when we view them

* The nearer an object is to the eye, the bigger it appears, and it is seen under the greater angle. To illustrate this a little, suppose an arrow in the position *IK*, perpendicular to the right line *HA*, drawn from the eye at *H* through the middle of the arrow at *O*. It is plain that the arrow is seen under the angle *IHK*, and that *HO*, which is its distance from the eye, divides into halves both the arrow and the angle under which it is seen, *viz.* the arrow into *IO*, *OK*; and the angle into *IHO* and *KHO*: and this will be the case at whatever distance the arrow is placed. Let now three arrows, all of the same length with *IK*, be placed at the distances *HA*, *HCE*, *H*, still perpendicular to, and bisected by the right line *HA*; then will *AB*, *CD*, *EF*, be each equal to, and represent *OI*, and *AB* (the same as *OI*) will be seen from *H* under the angle *AHB*; but *CD* (the same as *OI*) will be seen under the angle *CHD*, or *AHL*, and *EF* (the same as *OI*) will be seen under the angle *EHF*, or *CHN*, or *AHM*. Also *EF*, or *OI*, at the distance *HE*, will appear as long as *ON* would at the distance *HC*, or as *AM* would at the distance *HA*; and *CD*, or *IO*, at the distance *HC*, will appear as long as *AL* would at the distance *HA*. So that as an object approaches the eye, both its magnitude and the angle under which it is seen increase; and the contrary as the object recedes.

under equal degrees of brightness, and under equal angles; although they be objects whose bulks we are generally acquainted with, such as houses or trees; for proof of which, the two following instances may suffice:

First, When a house is seen over a very broad river by a person standing on a low ground, who sees nothing of the river, nor knows of it beforehand; the breadth of the river being hid from him, because the banks seem contiguous, he loses the idea of a distance equal to that breadth; and the house seems small because he refers it to a less distance than it really is at. But if he goes to a place from which the river and interjacent ground can be seen, though no farther from the house, he then perceives the house to be at a greater distance than he had imagined; and therefore fancies it to be bigger than he did at first; although in both cases it appears under the same angle, and consequently makes no bigger picture on the retina of his eye in the latter case than it did in the former. Many have been deceived by taking a red coat-of-arms, fixed upon the iron gate in *Clare-Hall* walks at *Cambridge*, for a brick house at a much greater distance.*

The reason assigned.

Plate II.

Secondly, In foggy weather, at first sight, we generally imagine a small house which is just at

* The fields which are beyond the gate rise gradually till they are just seen over it; and the arms being red, are often mistaken for a house at a considerable distance in those fields.

I once met with a curious deception in a gentleman's garden at *Hackney*, occasioned by a large pane of glass in the garden wall at some distance from his house. The glass (through which the sky was seen from low ground) reflected a very faint image of the house; but the image seemed to be in the clouds near the horizon, and at that distance looked as if it were a huge castle in the air.—Yet the angle, under which the image appeared, was equal to that under which the house was seen: but the image being mentally referred to a much greater distance than the house, appeared much bigger to the imagination.

Plate II. hand, to be a great castle at a distance; because it appears so dull and ill-defined when seen through the mist, that we refer it to a much greater distance than it really is at; and therefore, under the same angle, we judge it to be much bigger. For, the

Fig. XII.

near object *FE*, seen by the eye *A B D*, appears under the same angle *GCH* that the remote object *GHI* does: and the rays *G F C N* and *H E C M*, crossing one another at *C* in the pupil of the eye, limit the size of the picture *MN* on the retina, which is the picture of the object *FE*; and if *FE* were taken away, would be the picture of the object *GHI*, only worse defined; because *GHI* being farther off, appears duller and fainter than *FE* did. But when a fog, as *KL*, comes between the eye and the object *FE*, the object appears dull and ill-defined like *GHI*, which causes our imagination to refer *FE* to the greater distance *CH*, instead of the small distance *CE*, which it really is at. And consequently, as misjudging the distance does not in the least diminish the angle under which the object appears, the small hay-rick *FE* seems to be as big as *GHI*.

Fig. IX.

Why the Sun and Moon appear biggest in the horizon.

187. The Sun and Moon appear bigger in the horizon than at any considerable height above it. These luminaries, although at great distances from the Earth, appear floating, as it were, on the surface of our atmosphere *H G F f e C*, a little way beyond the clouds; of which those about *F*, directly over our heads at *E*, are nearer us than those about *H* or *e* in the horizon *HEe*. Therefore, when the Sun or Moon appears in the horizon at *e*, they are not only seen in a part of the sky, which is really farther from us than if they were at any considerable altitude, as about *f*; but they are also seen through a greater quantity of air and vapours at *e* than at *f*. Here we have two concurring appearances which deceive our imagination, and cause us to refer the Sun

and Moon to a greater distance at their rising or setting about *e*, than when they are considerably high as at *f*: first, their seeming to be on a part of the atmosphere at *e*, which is really farther than *f* from a spectator at *E*; and secondly, their being seen through a grosser medium, when at *e*, than when at *f*; which, by rendering them dimmer, causes us to imagine them to be at a yet greater distance. And as, in both cases, they are seen* much under the same angle, we naturally judge them to be biggest when they seem farthest from us; like the abovementioned house, § 186, seen from a higher ground, which shewed it to be farther off than it appeared from low ground; or the hay-rick, which appeared at a greater distance by means of an interposing fog.

188. Any one may satisfy himself that the Moon appears under no greater angle in the horizon than on the meridian, by taking a large sheet of paper, and rolling it up in the form of a tube, of such a width, that observing the Moon through it when she rises, she may, as it were, just fill the tube; then tie a thread round it to keep it of that size; and when the Moon comes to the meridian, and appears much less to the eye, look at her again through the same tube, and she will fill it just as much, if not more, than she did at her rising.

Their apparent diameters are not less on the meridian than in the horizon.

189. When the full Moon is in *perigee*, or at her least distance from the Earth, she is seen under a larger angle, and must therefore appear bigger than when she is full at other times; and if that part of the atmosphere where she rises be more replete with

* The Sun and Moon subtend a greater angle on the meridian than in the horizon, being nearer the observer's place in the former case than in the latter.

vapours than usual, she appears so much the dimmer; and therefore we fancy her to be still the bigger, by referring her to an unusually great distance; knowing that no objects which are very far distant can appear big unless they be really so.

CHAP. IX.

The Method of finding the Distances of the Sun, Moon, and Planets.

190. THOSE who have not learnt how to take the * altitude of any celestial phenomenon by a common quadrant, nor know any thing of plane trigonometry, may pass over the first article of this short chapter, and take the astronomer's word for it, that the distances of the Sun and planets are as stated in the first chapter of this book. But, to every one who knows how to take the altitude of the Sun, the Moon, or a star, and can solve a plane right

* The altitude of any celestial object, is an arc of the sky intercepted between the horizon and the object. In Fig. *VI.* of Plate *II.* let *HOX* be a horizontal line, supposed to be extended from the eye at *A* to *X*, where the sky and Earth seem to meet at the end of a long and level plane; and let *S* be the Sun. The arc *XY* will be the Sun's height above the horizon at A, and is found by the instrument *ECD*, which is a quadrantal board, or plate of metal, divided into 90 equal parts or degrees on its limb *DPC*, and has a couple of little brass plates, as *a* and *b*, with a small hole in each of them, called *sight-holes*, for looking through, parallel to the edge of the quadrant which they stand on. To the centre *E* is fixed one end of a thread *F*, called the *plumb-line*, which has a small weight or plummet *P* fixed to its other end. Now, if an observer hold the quadrant upright, without inclining it to either side, and so that the horizon at *X* is seen through the sight-holes *a* and *b*, the plumb-line will cut or hang over the beginning of the degrees at 0, in the edge *EC*; but if he elevate the quadrant so as to look through the sight-holes at any part of the heavens, suppose the Sun at *S*, just so many degrees as he elevates the sight-hole *b* above the horizontal line *HOX*,

angled triangle, the following method of finding the distances of the Sun and Moon will be easily understood. *Plate IV.*

Let *BAG* be one half of the Earth, *AC* its semidiameter, *S* the Sun, *m* the Moon, and *EKOL* a quarter of the circle described by the Moon in revolving from the meridian to the meridian again.—Let *CRS* be the rational horizon of an observer at *A*, extended to the Sun in the heavens; and *HAO* his sensible horizon, extended to the Moon's orbit. *ALC* is the angle under which the Earth's semidiameter *AC* is seen from the Moon at *L*, which is equal to the angle *OAL*, because the right lines *AO* and *CL*, which include both these angles, are parallel. *ASC* is the angle under which the Earth's semidiameter *AC* is seen from the Sun at *S*, and is equal to the angle *OAf*; because the lines *AO* and *CRS* are parallel. Now, it is found by observation, that the angle *OAL* is much greater than the angle *OAf*; but *OAL* is equal to *ALC*, and *OAf* is equal to *ASC*. Now, as *ASC* is much less than *ALC*, it proves that the Earth's semidiameter *AC* appears much greater as seen from the Moon at *L*, than from the Sun at *S*; and therefore the Earth is much farther from the Sun than from the Moon.* The *Fig. 1.*

so many degrees will the plumb-line cut in the limb *CP* of the quadrant. For, let the observer's eye at *A* be in the centre of the celestial arc *XYV*, (and he may be said to be in the centre of the Sun's apparent diurnal orbit, let him be on what part of the Earth he will) in which arc the Sun is at that time, suppose 25 degrees high, and let the observer hold the quadrant so that he may see the Sun through the sight-holes; the plumb-line freely playing on the quadrant will cut the 25th degree in the limb *CP*, equal to the number of degrees of the Sun's altitude at the time of observation.

N. B. Whoever looks at the Sun must have a smoked glass before his eyes to save them from hurt. The better way is not to look at the Sun through the sight-holes, but to hold the quadrant facing the eye at a little distance, and so that the Sun shining through one hole, the ray may be seen to fall on the other.

* See the Note on § 185.

quantities of these angles may be determined by observation in the following manner:

Let a graduated instrument, as *DAE*, (the larger the better,) having a moveable Index with sight-holes, be fixed in such a manner, that its plane surface may be parallel to the plane of the equator, and its edge *AD* in the plane of the meridian: so that when the Moon is in the equinoctial, and on the meridian *ADE*, she may be seen through the sight-holes when the edge of the moveable index cuts the beginning of the divisions at 0, on the graduated limb *DE*; and when she is so seen, let the *precise* time be noted. Now, as the Moon revolves about the Earth from the meridian to the meridian again in about 24 hours 48 minutes, she will go a fourth part round it in a fourth part of that time, *viz.* in six hours twelve minutes, as seen from *C*, that is, from the Earth's centre or pole. But as seen from *A*, the observer's place on the Earth's surface, the Moon will seem to have gone a quarter round the Earth when she comes to the sensible horizon at *O*; for the index through the sights of which she is then viewed, will be at *d*, 90 degrees from *D*, where it was when she was seen at *E*. Now let the exact moment when the Moon is seen at *O* (which will be when she is in or near the sensible horizon) be carefully noted*, that it may be known in what time she has gone from *E* to *O*; which time subtracted from 6 hours 12 minutes (the times of her going from *E* to *L*) leaves the time of her going from *O* to *L*, and affords an easy method for finding the angle *OAL*, (called *the Moon's horizontal parallax*, which is equal to the angle *ALC*) by the following analo-

The Moon's horizontal parallax what.

* Here proper allowance must be made for the refraction, which being about 34 minutes of a degree in the horizon, will cause the moon's centre to appear 34 minutes above the horizon when her centre is really in it.

gy: As the time of the Moon's describing the arc *EO* is to 90 degrees, so is 6 hours 12 minutes to the degrees of the arc *Dde*, which measures the angle *EAL*; from which subtract 90 degrees, and there remains the angle *OAL*, equal to the angle *ALC*, under which the Earth's semi-diameter *AC* is seen from the Moon. Now, since all the angles of a right-lined triangle are together equal to 180 degrees, or to two right angles, and the sides of a triangle are always proportional to the sines of the opposite angles, say by the *Rule of Three*, as the sine of the angle *ALC*, at the Moon *L*, is to its opposite side *AC*, the Earth's semi-diameter, which is known to be 3985 miles, so is radius, *viz.* the sine of 90 degrees, or of the right angle *ALC*, to its opposite side *AD*, which is the Moon's distance at *L* from the observer's place at *A*, on the Earth's surface; or, so is the sine of the angle *CAL* to its opposite side *CL*, which is the Moon's distance from the Earth's centre, and comes out at a mean rate to be 240,000 miles. The angle *CAL* is equal to what *OAL* wants of 90 degrees.

The Moon's distance determined.

191. The Sun's distance from the Earth might be found in the same way, though with more difficulty, if his horizontal parallax, or the angle *OAS*, equal to the angle *ASC*, were not so small, as to be hardly perceptible; being scarce 10 seconds of a minute, or the 360th part of a degree. But the Moon's horizontal parallax, or angle *OAL*, equal to the angle *ALC*, is very discernible, being 57′ 18″, or 3438″ at its mean state; which is more than 340 times as great as the Sun's: and, therefore, the distances of the heavenly bodies being inversely as the tangents of their horizontal parallaxes, the Sun's distance from the Earth is at least 340 times as great as the Moon's: and is rather underrated at 81 millions of miles, when the Moon's distance is certainly known to be 240 thousand. But

The Sun's distance cannot be yet so exactly determined as the Moon's.

because, according to some astronomers, the Sun's horizontal parallax, is 11 seconds, and according to others only 10, the former parallax making the Sun's distance to be about 75,000,000 of miles, and the latter 82,000,000; we may take it for granted that the Sun's distance is not less than as deduced from the former, nor more than as shewn by the latter: and every one, who is accustomed to make such observations, knows how hard it is, if not impossible, to avoid an error of a second, especially on account of the inconstancy of horizontal refractions. And here the error of one second, in so small an angle, will make an error of 7 millions of miles in so great a distance as that of the Sun's. But Dr. HALLEY has shewn us how the Sun's distance from the Earth, and consequently the distances of all the planets from the Sun, may be known to within a 500th part of the whole, by a transit of Venus over the Sun's disc, which will happen on the 6th of *June*, in the year 1761; till which time we must content ourselves with allowing the Sun's distance to be about 81 millions of miles, as commonly stated by astronomers.

How near the truth it may soon be determined.

The Sun proved to be much bigger than the Moon.

192. The Sun and Moon appear much about the same bulk; and every one who understands geometry, knows how their true bulks may be deduced from the apparent, when their real distances are known. Spheres are to one another as the cubes of their diameters; whence, if the Sun be 81 millions of miles from the Earth, to appear as big as the Moon, whose distance does not exceed 240 thousand miles, he must in solid bulk be 42 millions 875 thousand times as big as the Moon.

193. The horizontal parallaxes are best observed at the equator; 1. Because the heat is so nearly

equal every day, that the refractions are almost constantly the same. 2. Because the parallactic angle is greater there, as at *A*, (the distance from thence to the Earth's axis being greater,) than upon any parallel of latitude, as *a* or *b*.

194. The Earth's distance from the Sun being determined, the distances of all the other planets from him are easily found by the following analogy, their periods round him being ascertained by observation. As the square of the Earth's period round the Sun, is to the cube of its distance from the Sun; so is the square of the period of any other planet, to the cube of its distance in such parts or measures as the Earth's distance was taken; see § 111. This proportion gives the relative mean distances of the planets from the Sun to the greatest degree of exactness. They are as follows, having been deduced from their periodical times; according to the law just mentioned, which was discovered by KEPLER, and demonstrated by Sir ISAAC NEWTON.*

The relative distances of the planets from the Sun are known to great precision, though their real distances are not well known

* All the following calculations except those in the two last lines before § 195, were printed in former editions of this work, before the year 1761. Since that time the said two lines (as found by the transit A. D. 1761) were added; and also § 195.

Periodical Revolutions to the same fixed Star, in Days and Decimal Parts of a day.

Mercury	Venus	The Earth	Mars	Jupiter	Saturn	Georgian
87.9692	224.6176	365.2564	686.9785	4332.514	1079.275	30456.0[illegible]
Relative mean distances from the Sun.						
38710	72333	100000	152369	520096	954006	1908[illegible]
From these numbers we deduce, that if the Sun's horizontal parallax be 10″, the real mean distances of the planets from the Sun in English miles, are						
31,742,200	59,313,060	82,000,000	124,942,680	426,478,720	782,284,920	1,565,033,600
But if the Sun's parallax be 11″ their distances are no more than						
29,032,500	54,238,570	75,000,000	114,276,750	390,034,500	715,504,500	1,431,436,000
Errors in distance arising from the mistake of 1″ in the Sun's parallax						
2,709,700	5,074,490	7,000,000	10,665,930	36,444,220	66,780,420	133,600,000
But, from the late transit of Venus, A. D. 1761, the Sun's parallax appears to be only 8″ $\frac{65}{100}$; and according to that, their real distances in miles are						
36,841,468	68,891,486	9[illegible]3,127	145,014,148	494,990,976	907,956,130	1,816,455,[illegible]
And their diameters in miles, are,						
3100	9360	7970	5150	94,000	77,990	34,2[illegible]

195. These numbers shew, that although we have the relative distances of the planets from the Sun, to the greatest nicety, yet the best observers could not ascertain their true distances until the late long-wished-for transit appeared, in 1761, which we must confess was embarrassed with several difficulties. But another transit of Venus over the Sun, has now been observed, on the third of *June*, 1769, much better suited to the resolution of this great problem than that in 1761 was; and the result of the observations does not differ materially from the result of those in 1761. No other transit will happen till the year 1874.

196. The Earth's axis produced to the stars, being carried parallel* to itself during the Earth's annual revolution, describes a circle in the sphere of the fixed stars equal to the orbit of the Earth. But this orbit, though very large, would seem no bigger than a point, if it were viewed from the stars;

Why the celestial poles seem to keep still in

* By this is meant, that if a line be supposed to be drawn parallel to the Earth's axis in any part of its orbit, the axis keeps parallel to that line in every other part of its orbit: as in fig. I of plate V. where *a b c d e f g h* represents the Earth's orbit in an oblique view, and *N s* the Earth's axis keeping always parallel to the line *M.N.*

and consequently the circle described in the sphere of the stars by the axis of the Earth, produced, if viewed from the earth, must appear but as a point; that is, its diameter appears too little to be measured by observation: for Dr. BRADLEY has assured us, that if it had amounted to a single second, or two at most, he should have perceived it in the number of observations he has made, especially upon ♈ *Draconis;* and that it seemed to him very probable that the annual parallax of this star is not so great as a single second: and consequently, that it is above 400 thousand times farther from us than the Sun. Hence the celestial poles seem to continue in the same points of the heavens throughout the year; which by no means disproves the Earth's annual motion, but plainly proves the distance of the stars to be exceeding great.

the same points of the heavens, notwithstanding the Earth's motion round the Sun.

197. The small apparent motion of the stars, § 113, discovered by that great astronomer, he found to be no ways owing to their annual parallax, (for it came out contrary thereto,) but to the aberration of their light, which can result from no known cause, besides that of the Earth's annual motion; and as it agrees so exactly therewith, it proves beyond dispute, that the Earth has such a motion; for this aberration completes all its various phenomena every year; and proves that the velocity of star-light is such as carries it through a space equal to the Sun's distance from us in 8 minutes 13 seconds of time. Hence the velocity of light is *10 thousand 210 times as great as the Earth's velocity in its orbit; which velocity, (from what we know already of the Earth's distance from the Sun) may be asserted to be at least between 57 and 58 thousand miles every hour: and supposing it to be 58000, this number multiplied by 10210, gives 592 million 180 thousand miles for the hourly motion of light: which last number divided by 3600, the number of seconds in an hour,

The amazing velocity of light.

* SMITH's Optic's § 1197.

Plate IV. shews that light flies at the rate of more than 164 thousand miles every second of time, or swing of a common clock pendulum.

CHAP. X.

The Circles of the Globe described. The different Lengths of Days and Nights, and the Vicissitudes of the Seasons, explained. The explanation of the Phenomena of Saturn's Ring concluded. (See § 81 and 82.

Circles of the sphere. 198. IF the reader be hitherto unacquainted with the principal circles of the globe, he should now learn to know them; which he may do sufficiently for his present purpose in a quarter of an hour, if he sets the ball of a terrestrial globe before him, or looks at the figure of it, wherein these circles are drawn and named. The *equator* is that great circle which divides the northern half of the Earth from the southern. The *tropics* are lesser circles parallel to the equator; each of them being 23½ degrees from it; a degree in this sense being the 360th part of any great circle; or that which divides the Earth into two equal parts. The *tropic of Cancer* lies on the north side of the equator, and the *tropic of Capricorn* on the south. The *Arctic circle* has the *North pole* for its centre, and is just as far from it as the tropics are from the equator; and the *Antarctic circle*, (hid by the supposed convexity of the figure) is just as far from the *south pole* every way round it. These poles are the very north and south points of the globe: and all other places are denominated *northward* or *southward*, according to the side of the equator they lie on, and the pole to which they are nearest. The *Earth's axis* is a straight line passing through the centre of the Earth, perpendicular to the equator, and terminating in the poles at its surface. This, in the real Earth and planets, is only an imaginary line; but in artificial globes or planets it is a wire by which they are supported, and

Fig. II. Equator, tropics, polar circles, and poles. Fig. II. Earth's axis.

turned round in *Orreries*, or such like machines, by wheel-work. The circles 12. 1. 2. 3. 4. &c. are meridians to all places they pass through; and we must suppose thousands more to be drawn, because every place, that is ever so little to the east or west of any other place, has a different meridian from that other place. All the meridians meet in the poles; and whenever the Sun's centre is passing over any meridian in his apparent motion round the Earth, it is mid-day or noon to all places on that meridian. *Plate IV.* Meridians.

199. The *broad space* lying between the tropics, like a girdle surrounding the globe, is called the *torrid zone*, of which the equator is in the middle all round. The *space* between the tropic of Cancer and Arctic circle, is called the *north temperate zone; that* between the tropic of Capricorn and the Antarctic circle, the *south temperate zone;* and the two *circular spaces* bounded by the polar circles, are the two *frigid zones;* denominated *north* or *south*, from that pole which is in the centre of the one or the other of them. Zones.

200. Having acquired this easy branch of knowledge, the learner may proceed to make the following experiment with his terrestrial ball; which will give him a plain idea of the diurnal and annual motions of the Earth, together with the different lengths of days, nights, and all the beautiful variety of seasons, depending on those motions.

Take about seven feet of strong wire, and bend it into a circular form, as *abcd*, which being viewed obliquely, appears elliptical, as in the figure. Place a lighted candle on a table, and having fixed one end of a silk thread *K*, to the north pole of a small terrestrial globe *H*, about three inches diameter, cause another person to hold the wire-circle, so that it may be parallel to the table, and as high as the flame of the candle *I*, which should be in or near the Fig. III. A pleasing experiment shewing the different lengths of days and nights, and the variety of seasons.

centre. Then, having twisted the thread as toward the left hand, that by untwisting it may turn the globe round eastward, or contrary to the way that the hands of a watch move, hang the globe by the thread within this circle, almost contiguous to it; and as the thread untwists, the globe (which is enlightened half round by the candle, as the Earth is by the Sun) will turn round its axis, and the different places upon it will be carried through the light and dark hemispheres, and have the appearance of a regular succession of days and nights, as our Earth has in reality by such a motion. As the globe turns, move your hand slowly, so as to carry the globe round the candle according to the order of the letters *abcd*, keeping its centre even with the wire-circle; and you will perceive, that the candle, being still perpendicular to the equator, will enlighten the globe from pole to pole in its whole motion round the circle; and that every place on the globe goes equally through the light and the dark, as it turns round by the untwisting of the thread, and therefore has a perpetual equinox. The globe thus turning round represents the Earth turning round its axis; and the motion of the globe round the candle represents the Earth's annual motion round the Sun, and shews, that if the Earth's orbit had no inclination to its axis, all the days and nights of the year would be equally long, and there would be no different seasons. But now, desire the person who holds the wire to hold it obliquely in the position *ABCD*, raising the side ♋ just as much as he depresses the side ♑, that the flame may be still in the plane of the circle; and twisting the thread as before, that the globe may turn round its axis the same way as you carry it round the candle, that is, from west to east, let the globe down into the lowermost part of the wire circle at ♑, and if the circle be properly inclined, the candle will shine perpendicular

cularly on the tropic of Cancer, and the *frigid zone*, Summer
lying within the *Arctic* or *north polar circle*, will be solstice.
all in the light, as in the figure; and will keep in the light, let the globe turn round its axis ever so often. From the equator to the north polar circle all the places have longer days and shorter nights; but from the equator to the south polar circle just the reverse. The Sun does not set to any part of the north frigid zone, as shewn by the candle's shining on it, so that the motion of the globe can carry no place of that zone into the dark: and at the same time the *south frigid zone* is involved in darkness, and the turning of the globe brings none of its places into the light. If the Earth were to continue in the like part of its orbit, the Sun would never set to the inhabitants of the north frigid zone, nor rise to those of the south. At the equator it would be always equal day and night; and as places are gradually more and more distant from the equator, toward the Arctic circle, they would have longer days and shorter nights; while those on the south side of the equator would have their nights longer than their days. In this case there would be continual summer on the north side of the equator, and continual winter on the south side of it.

But as the globe turns round its axis, move your hand slowly forward, so as to carry the globe from *H* toward *E*, and the boundary of light and darkness will approach toward the north pole, and recede from the south pole; the northern places will go through less and less of the light, and the southern places through more and more of it; shewing how the northern days decrease in length, and the southern days increase, while the globe proceeds from *H* to *E*. When the globe is at *E*, it is at a
mean state between the lowest and highest parts of Autumnal
its orbit; the candle is directly over the equator, the equinox.
boundary of light and darkness just reaches to both

T

the poles, and all places on the globe go equally through the light and dark hemispheres, shewing that the days and nights are then equal at all places of the Earth, the poles only excepted; for the Sun is then setting to the north pole, and rising to the south pole.

Continue moving the globe forward, and as it goes through the quarter *A*, the north-pole recedes still farther into the dark hemisphere, and the south pole advances more into the light, as the globe comes nearer to ♋: and when it comes there at *F*, the candle is directly over the tropic of Capricorn, the days are at the shortest, and nights at the longest, in the northern hemisphere, all the way from the equator to the Arctic circle; and the reverse in the southern hemisphere from the equator to the Antarctic circle; within which circles it is dark to the north frigid zone, and light to the south.

Winter solstice.

Continue both motions, and as the globe moves through the quarter *B*, the north pole advances toward the light, and the south pole toward the dark; the days lengthen in the northern hemisphere, and shorten in the southern; and when the globe comes to *G*, the candle will be again over the equator, (as when the globe was at *E*.) and the days and nights will again be equal as formerly; and the north pole will be just coming into the light, the south pole going out of it.

Vernal equinox.

Thus we see the reason why the days lengthen and shorten from the equator to the polar circles every year; why there is sometimes no day or night for many turnings of the Earth, within the polar circles; why there is but one day and one night in the whole year at the poles; and why the days and nights are equally long all the year round at the equator, which is always equally cut by the circle bounding light and darkness.

201. The inclination of an axis or orbit is merely relative, because we compare it with some other axis or orbit which we consider as not inclined at all. Thus, our horizon being level to us, whatever place of the Earth we are upon, we consider it as having no inclination; and yet, if we travel 90 degrees from that place, we shall then have a horizon perpendicular to the former, but it will still be level to us. And if this book be held so that the * circle *ABCD* be parallel to the horizon, both the circle *abcd*, and the thread or axis *K*, will be inclined to it. But if the book or plate be held so that the thread be perpendicular to the horizon, then the orbit *ABCD* will be inclined to the thread, and the orbit *abcd* perpendicular to it, and parallel to the horizon. We generally consider the Earth's annual orbit as having no inclination, and the orbits of all the other planets as inclined to it, § 20. **Remark.** Plate III. Fig. III.

202. Let us now take a view of the Earth in its annual course round the Sun, considering its orbit as having no inclination, and its axis as inclining 23½ degrees from a line perpendicular to the plane of its orbit, and keeping the same oblique direction in all parts of its annual course; or, as commonly termed, keeping always parallel to itself, § 196.

Let *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, be the Earth in eight different parts of its orbit, equidistant from one another: *N s* its axis, *N* its north pole, *s* its south pole, and *S* the Sun nearly in the centre of the Earth's orbit, § 18. As the Earth goes round the Sun according *Plate V.* Fig. I.

* All circles appear elliptical in an oblique view, as is evident by looking obliquely at the rim of a bason. For the true figure of a circle can only be seen when the eye is directly over its centre. The more obliquely it is viewed, the more elliptical it appears, until the eye be in the same plane with it, and then it appears like a straight line.

Plate V. to the order of the letters *abcd*, &c. its axis *N s* keeps the same obliquity, and is still parallel to the line *M N s*. When the Earth is at *a*, its north pole inclines toward the Sun *S*, and brings all the northern places more into the light than at any other time of the year. But when the Earth is at *e* in the opposite time of the year, the north pole declines from the Sun, which occasions the northern places to be more in the dark than in the light; and the reverse at the southern places, as is evident by the figure, which I have taken from Dr. LONG's Astronomy. When the Earth is either at *c* or *g*, its axis inclines not either to or from the Sun, but lies sidewise to him; and then the poles are in the boundary of light and darkness; and the Sun, being directly over the equator, makes equal day and night at all places. When the Earth is at *b*, it is half-way between the Summer solstice and harvest equinox; when it is at *d*, it is half way from the harvest equinox to the winter solstice; at *s*, half way from the winter solstice to the spring equinox; and at *h*, half way from the spring equinox to the summer solstice.

A concise view of the seasons.

Fig. II. 203. From this oblique view of the Earth's orbit, let us suppose ourselves to be raised far above it, and placed just over its centre *S*, looking down upon it from its north pole; and as the Earth's orbit differs but very little from a circle, we shall have its figure in such a view represented by the circle *ABCDEFGH*. Let us suppose this circle to be divided into 12 equal parts, called *signs*, having their names affixed to them: and each sign into 30 equal parts, called *degrees*, numbered 10, 20, 30, as in the outermost circle of the figure, which represents the great ecliptic in the heavens. The Earth is shewn in eight different positions in this circle: and in each position *Æ* is the equator, *T* the tropic of Cancer, the *dotted circle*

The seasons shewn in another view of the Earth and its orbit.

the parallel of *London*, *U* the Arctic or north polar circle, and *P* the north pole, where all the meridians or hour-circles meet, § 198. As the Earth goes round the Sun, the north pole keeps constantly toward one part of the heavens, as it does in the figure toward the right-hand side of the plate.

When the Earth is at the beginning of Libra, namely, on the 20th of *March* in this figure (as at *g* in Fig. I.) the Sun *S*, as seen from the Earth, appears at the beginning of Aries, in the opposite part of the heavens*, the north pole is just coming into the light, and the Sun is vertical to the equator; which, together with the tropic of Cancer, parallel of *London*, and Arctic circle, are all equally cut by the circle bounding light and darkness, coinciding with the six o'clock hour-circle, and therefore the days and nights are equally long at all places: for every part of the meridians *ÆTLa* comes into the light at six in the morning, and revolving with the Earth according to the order of the hour-letters goes into the dark at six in the evening. There are 24 meridians, or hour-circles drawn on the Earth in this figure, to shew the time of sun-rising and setting at different seasons of the year. Vernal equinox.

As the Earth moves in the ecliptic according to the order of the letters *ABCD*, &c. through the signs, Libra, Scorpio, and Sagittarius, the north pole *P* comes more and more into the light; the days increase as the nights decrease in length at all places north of the equator *Æ*; which is plain by viewing the Earth at *b* on the 5th of *May*, when it is in the 15th degree of Scorpio †, and the Sun, as

* Here we must suppose the Sun to be no bigger than an ordinary point (as .) because he only covers a circle half a degree in diameter in the heavens; whereas in the figure he hides a whole sign at once from the Earth.

† Here we must suppose the Earth to be a much smaller point than that in the preceding note marked for the Sun.

Plate V. seen from the Earth, appears in the 15th degree of Taurus. For then, the tropic of Cancer *T* is in the
Fig. II. light from a little after five in the morning till almost seven in the evening; the parallel of *London* from half an hour past four till half an hour past seven; the polar circle *U* from three till nine; and a large track round the north pole *P* has day all the 24 hours, for many rotations of the Earth on its axis.

When the Earth comes to *c*, at the beginning of Capricorn, and the Sun, as seen from the Earth appears at the beginning of Cancer, on the 21st of *June*, as in this figure, it is in the position *a* in Fig. I; and its north pole inclines toward the Sun, so as to bring all the north frigid zone into the light, and the northern parallels of latitude more into the light than the dark from the equator to the polar circle; and the more so as they are farther from the equator. The tropic of Cancer is in the light from five in the morning till seven at night; the parallel of *London* from a quarter before four till a quarter after eight; and the polar circle just touches the dark, so that the
Summer solstice. Sun has only the lower half of his disc hid from the inhabitants on that circle for a few minutes about midnight, supposing no inequalities in the horizon, and no refraction.

A bare view of the figure is enough to shew, that as the Earth advances from Capricorn toward Aries, and the Sun appears to move from Cancer toward Libra, the north pole advances toward the dark, which causes the days to decrease, and the nights to
Autumnal Equinox. increase in length, till the Earth comes to the beginning of Aries, and then they are equal as before; for the boundary of light and darkness cuts the equator and all its parallels equally, or in halves. The north pole then goes into the dark, and continues in it until the Earth goes half way round its orbit; or, from the 23d of *September* till the 20th of *March*. In the

middle, between these times, *viz.* on the 22d of *December*, the north pole is as far as it can be in the dark, which is 23½ degrees, equal to the inclination of the Earth's axis from a perpendicular to its orbit: and then the northern parallels are as much in the dark as they were in the light on the 21st of *June;* the winter nights being as long as the summer days, and the winter days as short as the summer nights. It is needless to enlarge farther on this subject, as we shall have occasión to mention the seasons again in describing the *Orrery*, § 397. Only this must be noted, that whatever has been said of the northern hemisphere, the contrary must be understood of the southern; for on different sides of the equator the seasons are contrary; because, when the northern hemisphere inclines toward the Sun, the southern declines from him. Winter solstice.

204. As Saturn goes round the Sun, his obliquely-posited ring, like our Earth's axis, keeps parallel to itself, and is therefore turned edgewise to the Sun twice in a Saturnian year; which is almost as long as 30 of our years, § 81. But the ring, though considerably broad, is too thin to be seen by us when it is turned edgewise to the Sun, at which time it is also edgewise to the Earth; and therefore it disappears once in every fifteen years to us. As the Sun shines half a year together on the north pole of our Earth, then disappears to it, and shines as long on the south pole; so, during one half of Saturn's year, the Sun shines on the north side of his ring, then disappears to it, and shines as long on the south side. When the Earth's axis inclines neither to nor from the Sun, but is sidewise to him, he then ceases to shine on one pole, and begins to enlighten the other; and when Saturn's ring inclines neither to nor from the Sun, but is edgewise to him, The phenomena of Saturn's ring.

Plate V. he ceases to shine on the one side of it, and begins to shine upon the other.

Fig. III. Let *S* be the *Sun*, *ABCDEFGH* Saturn's orbit, and *IKLMNO* the Earth's orbit. Both Saturn and the Earth move according to the order of the letters: when Saturn is at *A* his ring is turned edgewise to the Sun *S*, and he is then seen from the Earth as if he had lost his ring, let the Earth be in any part of its orbit whatever, except between *N* and *O*; for while it describes that space, Saturn is apparently so near the Sun as to be hid in his beams. As Saturn goes from *A* to *C*, his ring appears more and more open to the Earth: at *C* the ring appears most open of all; and seems to grow narrower and narrower, as Saturn goes from *C* to *E*, and when he comes to *E*, the ring is again turned edgewise both to the Sun and Earth; and as neither of its sides are illuminated, it is invisible to us, because its edge is too thin to be perceptible; and Saturn appears again as if he had lost his ring. But as he goes from *E* to *G*, his ring opens more and more to our view on the under side; and seems just as open at *G* as it was at *C*; and may be seen in the night time from the Earth in any part of its orbit, except about *M*, when the Sun hides the planet from our view. As Saturn goes from G to *A*, his ring turns more and more edgewise to us, and therefore it seems to grow narrower and narrower; and at *A*, it disappears as before. Hence, while Saturn goes from *A* to *E*, the Sun shines on the upper side of his ring, and the under side is dark; and while he goes from *E* to *A*, the Sun shines on the under side of his ring, and the upper side is dark.

It may perhaps be imagined that this article might have been placed more properly after § 81, than here; but when the candid reader considers Fig. I. and III. that all the various phenomena of Saturn's ring depend upon a cause similar to that of our Earth's

seasons, he will readily allow that they are best explained together; and that the two figures serve to illustrate each other. *Plate VI.*

The Earth nearer the Sun in winter than in Summer.

205. The Earth's orbit being elliptical, and the Sun keeping constantly in its lower focus, which is 1,377,000 miles from the middle point of the longer axis, the Earth comes twice so much, or 2,754,000 miles, nearer the Sun at one time of the year than at another: for the Sun appearing to us under a larger angle in winter than in summer, proves that the Earth is nearest the Sun in winter *(see the Note on Article* 185*)*. But here this natural question will arise: Why have we not the hottest weather when the Earth is nearest the Sun? In answer it must be observed, that the eccentricity of the Earth's orbit, or 1,377,000 miles, bears no greater proportion to the Earth's mean distance from the Sun, than 17 does to 1000; and therefore this small difference of distance cannot occasion any sensible difference of heat or cold. But the principal cause of this difference is, that in winter the Sun's rays fall so obliquely upon us, that any given number of them is spread over a much greater portion of the Earth's surface where we live, and therefore each point must then have fewer rays than in summer. Moreover, there comes a greater degree of cold in the long winter nights, than there can return of heat in so short days; and on both these accounts the cold must increase. But in summer the Sun's rays fall more perpendicularly upon us, and therefore come with greater force, and in greater numbers on the same place; and by their long continuance, a much greater degree of heat is imparted by day than can fly off by night.

Why the weather is coldest when the Earth is nearest the Sun.

206. That a greater number of rays fall on the same place, when they come perpendicularly, than when they come obliquely on it, will appear by the figure. For, let *AB* be a certain number of the Sun's rays falling on *CD* (which let us suppose to Fig. II.

be *London)* on the 21st of *June:* but, on the 22d of *December*, the line *CD*, or *London*, has the oblique position *CD* to the same rays; and therefore scarce a third part of them falls upon it, or only those between *A* and *e;* all the rest, *c B*, being expended on the space *d P*, which is more than double the length of *CD* or *Cd*. Besides, those parts which are once heated, retain the heat for some time; which, with the additional heat daily imparted, makes it continue to increase, though the Sun declines toward the south; and this is the reason why *July* is hotter than *June*, although the Sun has withdrawn from the summer tropic; as we find it is generally hotter at three in the afternoon, when the Sun has gone toward the west, than at noon when he is on the meridian. Likewise, those places which are well cooled require time to be heated again; for the Sun's rays do not heat even the surface of any body till they have been some time upon it. And therefore we find *January*, for the most part, colder than *December*, although the Sun has withdrawn from the winter tropic, and begins to dart his beams more perpendicularly upon us, when we have the position *CF*. An iron bar is not heated immediately upon being put into the fire, nor grows cold till some time after it has been taken out.

CHAP. XI.

The Method of finding the Longitude by the Eclipses of Jupiter's Satellites: the amazing Velocity of Light demonstrated by these Eclipses.

First meridian, and longitude of places, what.

207. GEOGRAPHERS arbitrarily choose to call the meridian of some remarkable place *the first meridian*. There they begin their reckoning; and just so many degrees and minutes as any other place is to the eastward or westward of that meridian, so much east or west longitude they say it has. A degree is the 360th part of a circle,

be it great or small, and a minute the 60th part of a degree. The *English* geographers reckon the longitude from the meridian of the Royal Observatory at *Greenwich*, and the *French* from the meridian of *Paris*. *Plate V.*

208. If we imagine two great circles, one of which is the meridian of any given place, to intersect each other in the two poles of the Earth, and to cut the equator *Æ* at every 15th degree, they will be divided by the poles into 24 semi-circles, which divide the equator into 24 equal parts; and as the Earth turns on its axis, the planes of these semicircles come successively one after another every hour to the Sun. As in an hour of time there is a revolution of fifteen degrees of the equator, in a minute of time there will be a revolution of 15 minutes of the equator, and in a second of time a revolution of 15 seconds. There are two tables annexed to this chapter, for reducing mean solar time into degrees and minutes of the terrestrial equator; and also for converting degrees and parts of the equator into mean solar time. Fig. II. Hour circles. An hour of time equal to 15 degrees of motion.

209. Because the Sun enlightens only one half of the Earth at once, as it turns round its axis, he rises to some places at the same moment of absolute time that he sets at to others; and when it is mid-day to some places, it is mid-night to others. The XII on the middle of the Earth's enlightened side, next the Sun, stands for mid-day; and the opposite XII, on the middle of the dark side for midnight. If we suppose this circle of hours to be fixed in the plane of the equinoctial, and the Earth to turn round within it, any particular meridian will come to the different hours so as to shew the true time of the day or night at all places on that meridian. Therefore,

210. To every place 15 degrees eastward from any given meridian, it is noon an hour sooner than on that meridian; because their meridian comes

to the Sun an hour sooner; and to all places 15 degrees westward, it is noon an hour later, § 208, because their meridian comes an hour later to the Sun; and so on; every 15 degrees of motion causing an hour's difference of time. Therefore they who have noon an hour later than we, have their meridian, that is their longitude, 15 degrees westward from us; and they who have noon an hour sooner than we, have their meridian 15 degrees eastward from ours; and so for every hour's difference of time, 15 degrees difference of longitude. Consequently, if the beginning or ending of a lunar eclipse be observed, suppose at *London*, to be exactly at midnight, and in some other place at 11 at night, that place is 15 degrees westward from the meridian of *London*; if the same eclipse be observed at one in the morning at another place, that place is 15 degrees eastward from the said meridian.

And consequently to 15 degrees of longitude.

Lunar eclipses useful in finding the longitude.

Eclipses of Jupiter's satellites much better for that purpose.

211. But as it is not easy to determine the exact moment either of the beginning or ending of a lunar eclipse, because the Earth's shadow through which the Moon passes is faint and ill-defined about the edges, we have recourse to the eclipses of Jupiter's satellites, which disappear much more quickly as they enter into Jupiter's shadow, and emerge more suddenly out of it. The first or nearest satellite to Jupiter is the most advantageous for this purpose, because its motion is quicker than the motion of any of the rest, and therefore its immersions and emersions are more frequent and more sudden than those of the others are.

212 The *English* astronomers have calculated tables for shewing the times of the eclipses of Jupiter's satellites to great precision, for the meridian of *Greenwich*. Now, let an observer, who has these tables, with a good telescope and a well-regulated clock, at any other place of the Earth, observe the

beginning or ending of an eclipse of one of Jupiter's satellites, and note the precise moment of time that he saw the satellite either immerge into, or emerge out of the shadow, and compare that time with the time shewn by the tables for *Greenwich*; then, 15 degrees difference of longitude being allowed for every hour's difference of time, will give the longitude of that place from *Greenwich*, as above, § 210: and if there be any odd minutes of time, for every minute a quarter of a degree, east or west, must be allowed, as the time of observation is later or earlier than the time shewn by the tables. Such eclipses are very convenient for this purpose on land, because they happen almost every day; but are of no use at sea, because the rolling of the ship hinders all nice telescopical observations.

Plate V. How to solve this important problem.

213. To explain this by a figure, let *J* be Jupiter, *K*, *L*, *M*, *N*, his four satellites in their respective orbits, 1, 2, 3, 4; and let the Earth be at *f*, suppose in *November*, although that month is no otherwise material than to find the Earth readily in this scheme, where it is shewn in eight different parts of its orbit. Let *Q* be a place on the meridian of *Greenwich*, and *R* a place on some other meridian eastward from *Greenwich*. Let a person at *R* observe the instantaneous vanishing of the first satellite *K* into Jupiter's shadow, suppose at three in the morning; but by the tables he finds the immersion of that satellite to be at midnight at *Greenwich*; he can then immediately determine, that, as there are three hours difference of time between *Q* and *R*, and that *R* is three hours forwarder in reckoning than *Q*, it must be in 45 degrees of east longitude from the meridian of *Q*. Were this method as practicable at sea as on land, any sailor might almost as easily, and with almost equal certainty, find the longitude as the latitude.

Fig. II. Illustrated by an example.

214. While the Earth is going from *C* to *F* in its orbit, only the immersion of Jupiter's satellites

Fig. II.

We seldom see the beginning and end of the same eclipse of any of Jupiter's moons.

into his shadow are generally seen; and their emersions out of it while the Earth goes from *G* to *B*.—Indeed, both these appearances may be seen of the second, third and fourth satellite when eclipsed, while the Earth is between *D* and *E*, or between *G* and *A*; but never of the first satellite, on account of the smallness of its orbit and the bulk of Jupiter, except only when Jupiter is directly opposite to the Sun, that is, when the Earth is at *g*: and even then, strictly speaking, we cannot see either the immersions or emersions of any of his satellites, because his body being directly between us and his conical shadow his satellites are hid by his body a few moments before they touch his shadow; and are quite emerged from thence before we can see them, as it were, just dropping from behind him. And when the Earth is at *c*, the Sun, being between it and Jupiter, hides both him and his moons from us.

In this diagram, the orbits of Jupiter's moons are drawn in true proportion to his diameter; but in proportion to the Earth's orbit, they are drawn 81 times too large.

Jupiter's conjunctions with the Sun, or oppositions to him, are every year in different parts of the heavens.

215. In whatever month of the year Jupiter is in conjunction with the Sun, or in opposition to him, in the next year it will be a month later at least. For while the earth goes once round the Sun, Jupiter describes a twelfth part of his orbit. And, therefore, when the Earth has finished its annual period from being in a line with the Sun and Jupiter, it must go as much forwarder as Jupiter has moved in that time, to overtake him again: just like the minute-hand of a watch, which must, from any conjunction with the hour-hand, go once round the dial-plate and somewhat above a twelfth part more, to overtake the hour-hand again.

216. It is found by observation, that when the Earth is between the Sun and Jupiter, as at *g*, his

satellites are eclipsed about 8 minutes sooner than *Plate IV.* they should be according to the tables; and when the Earth is at *B* or *C*, these eclipses happen about 8 minutes later than the tables predict them.* Hence it is undeniably certain, that the motion of light is not instantaneous, since it takes about 16·½ minutes of time to go through a space equal to the diameter of the Earth's orbit which is 190 millions of miles in length; and consequently the particles of light fly about 193 thousand 939 miles every second of time, which is above a million of times swifter than the motion of a cannon ball. And as light is 16¼ minutes in travelling across the Earth's orbit, it must be 8¼ minutes coming from the Sun to us; therefore, if the Sun were annihilated, we should see him for 8¼ minutes after; and if he were again created, he would be 8¼ minutes old before we could see him.

The surprising velocity of light.

217. To explain the progressive motion of light, let *A* and *B* be the Earth, in two different parts of its orbit, whose distance from each other is 95 millions of miles, equal to the Earth's distance from the Sun *S*. It is plain that if the motion of light were instantaneous, the satellite 1 would appear to enter into Jupiter's shadow *FF* at the same moment of time to a spectator in *A* as to another in *B*. But by many years observations it has been found, that the immersion of the satellite into the shadow is seen 8¼ minutes sooner when the Earth is at *B*, than when it is at *A*. And so, as Mr. Roemer first discovered, the motion of Light is thereby proved to be progressive, and not instantaneous, as was formerly believed. It is easy to compute in what time the Earth moves from *A* to *B*; for the chord of 60 degrees of any circle is equal to the semi-diameter of that circle; and as the Earth goes through

Fig. V. Illustrated by a figure.

* In the tables which have been published in the nautical almanacs, &c. a proper allowance for the progress of light is made.

all the 360 degrees of its orbit in a year, it goes through 60 of those degrees in about 61 days.—Therefore, if on any given day, suppose the first of *June*, the Earth be at *A*, on the first of *August* it will be at *B*: the chord, or straight line *AB*, being equal to *DS*, the radius of the Earth's orbit, the same with *AS*, its distance from the Sun.

218. As the Earth moves from *D* to *C*, through the side *AB* of its orbit, it is constantly meeting the light of Jupiter's satellites sooner, which occasions an apparent acceleration of their eclipses: and as it moves through the other half *H* of its orbit from *C* to *D*, it is receding from their light, which occasions an apparent retardation of their eclipses; because their light is then longer before it overtakes the Earth.

219. That these accelerations of the immersions of Jupiter's satellites into his shadow, as the Earth approaches toward Jupiter, and the retardations of their emersions out of his shadow, as the Earth is going from him, are not occasioned by any inequality arising from the motions of the satellites in eccentric orbits, is plain, because it affects them all alike, in whatever parts of their orbits they are eclipsed. Besides, they go often round their orbits every year, and their motions are no way commensurate to the Earth's. Therefore, a phenomenon, not to be accounted for from the real motions of the satellites, but so easily deducible from the Earth's motion, and so answerable thereto, must be allowed to result from it. This affords one very good proof of the Earth's annual motion.

200. Tables for converting mean solar Time into Degrees and Parts of the terrestrial Equator; and also for converting Degrees and Parts of the Equator into mean solar Time.

Table I. For converting Time into Degrees and Parts of the Equator.								Table II. For converting Degrees and Parts of the Equator into Time.								
Hours	Degrees	Min. / Sec / Thirds	Deg. / Min. / Sec.	Min. / Sec. / Thirds	Min. / Sec. / Thirds	Deg / Min. / Sec.	Min. / Sec. / Thirds	Deg. / Min. / Sec.	Hours / Min. / Sec.	Min. / Sec. / Thirds	Deg / Min. / Sec.	Hours / Min / Sec	Min. / Sec. / Thirds	Degrees	Hours	Minutes
1	15	1	0	15	31	7	45	1	0	4	31	2	4	70	4	40
2	30	2	0	30	32	8	0	2	0	8	32	2	8	80	5	20
3	45	3	0	45	33	8	15	3	0	12	33	2	12	90	6	0
4	60	4	1	0	34	8	30	4	0	16	34	2	16	100	6	40
5	75	5	1	15	35	8	45	5	0	20	35	2	20	110	7	20
6	90	6	1	30	36	9	0	6	0	24	36	2	24	120	8	0
7	105	7	1	45	37	9	15	7	0	28	37	2	28	130	8	40
8	120	8	2	0	38	9	30	8	0	32	38	2	32	140	9	20
9	135	9	2	15	39	9	45	9	0	36	39	2	36	150	10	0
10	150	10	2	30	40	10	0	10	0	40	40	2	40	160	10	40
11	165	11	2	45	41	10	15	11	0	44	41	2	44	170	11	20
12	180	12	3	0	42	10	30	12	0	48	42	2	48	180	12	0
13	195	13	3	15	43	10	45	13	0	52	43	2	52	190	12	40
14	210	14	3	30	44	11	0	14	0	56	44	2	56	200	13	20
15	225	15	3	45	45	11	15	15	1	0	45	3	0	210	14	0
16	240	16	4	0	46	11	30	16	1	4	46	3	4	220	14	40
17	255	17	4	15	47	11	45	17	1	8	47	3	8	230	15	20
18	270	18	4	30	48	12	0	18	1	12	48	3	12	240	16	0
19	285	19	4	45	49	12	15	19	1	16	49	3	16	250	16	40
20	300	20	5	0	50	12	30	20	1	20	50	3	20	260	17	20
21	315	21	5	15	51	12	45	21	1	24	51	3	24	270	18	0
22	330	22	5	30	52	13	0	22	1	28	52	3	28	280	18	40
23	345	23	5	45	53	13	15	23	1	32	53	3	32	290	19	20
24	360	24	6	0	54	13	30	24	1	36	54	3	36	300	20	0
25	375	25	6	15	55	13	45	25	1	40	55	3	40	310	20	40
26	390	26	6	30	56	14	0	26	1	44	56	3	44	320	21	20
27	405	27	6	45	57	14	15	27	1	48	57	3	48	330	22	0
28	420	28	7	0	58	14	30	28	1	52	58	3	52	340	22	40
29	430	29	7	15	59	14	45	29	1	56	59	3	56	350	23	20
30	450	30	7	30	60	15	0	30	2	0	60	4	0	360	24	0

These are the tables mentioned in the 208th Article, and are so easy that they scarce require any farther explanation than to inform the reader, that if, in Table I. he reckon the columns marked with asterisks to be minutes of time, the other columns give the equatorial parts or motion in degrees and minutes; if he reckon the asterisk-columns to be seconds, the others give the motion in minutes and seconds of the equator; if thirds, in seconds and thirds: And if in Table II. he reckon the asterisk-columns to be degrees of motion, the others give the time answering thereto in hours and minutes; if minutes of motion, the time is minutes and seconds; if seconds of motion, the corresponding time is given in seconds and thirds. An example in each case will make the whole very plain.

EXAMPLE I.

In 10 hours 15 minutes 24 seconds 20 thirds, *Qu.* How much of the equator revolves through the meridian?

		Deg.	M.	S.
Hours	10	150	0	0
Min.	15	3	45	0
Sec.	24		6	0
Thirds	20			5
Answer		153	51	5

EXAMPLE II.

In what time will 153 degrees 51 minutes 5 seconds of the equator revolve through the meridian?

		H.	M.	S.	T.
Deg.	150	10	0	0	0
Deg.	3		12	0	0
Min.	51		3	24	0
Sec.	5				20
Answer		10	15	24	20

CHAP. XII.

Of Solar and Sidereal Time.

Sidereal days shorter than solar days, and why.

221. THE stars appear to go round the Earth in 23 hours 56 minutes 4 seconds, and the Sun in 24 hours: so that the stars gain three minutes 56 seconds upon the Sun every day, which

amounts to one diurnal revolution in a year; and therefore, in 365 days, as measured by the returns of the Sun to the meridian, there are 366 days, as measured by the stars returning to it: the former are called *solar days*, and the latter *sidereal days*. *Plate III.*

The diameter of the Earth's orbit is but a physical point in proportion to the distance of the stars; for which reason, and the Earth's uniform motion on its axis, any given meridian will revolve from any star to the same star again in every absolute turn of the Earth on its axis, without the least perceptible difference of time shewn by a clock which goes exactly true.

If the Earth had only a diurnal motion, without an annual, any given meridian would revolve from the Sun to the Sun again in the same quantity of time as from any star to the same star again; because the Sun would never change his place with respect to the stars. But, as the Earth advances almost a degree eastward in its orbit in the time that it turns eastward round its axis, whatever star passes over the meridian on any day with the Sun, will pass over the same meridian on the next day when the Sun is almost a degree short of it; that is, 3 minutes 56 seconds sooner. If the year contained only 360 days, as the ecliptic does 360 degrees, the Sun's apparent place, so far as his motion is equable, would change a degree every day; and then the sidereal days would be just 4 minutes shorter than the solar.

Let *ABCDEFGHIKLM* be the Earth's orbit, in which it goes round the Sun every year, according to the order of the letters, that is, from west to east; and turns round its axis the same way from the Sun to the Sun again in every 24 hours. Let *S* be the Sun, and *R* a fixed star at such an immense distance, that the diameter of the Earth's orbit bears no sensible proportion to that distance. Let *N m* be any particular meridian of the Earth, and *N* a given point or place upon that meridian. *Fig. II*

When the Earth is at *A* the Sun *S* hides the star *R*, which would be always hid if the Earth never removed from *A*; and consequently, as the Earth turns round its axis, the point *N* would always come round to the Sun and star at the same time. But when the Earth has advanced, suppose a twelfth part of its orbit from *A* to *B*, its motion round its axis will bring the point *N* a twelfth part of a natural day, or two hours, sooner to the star than to the Sun, for the angle *N B n* is equal to the angle *ASB*: and therefore any star which comes to the meridian at noon with the Sun when the Earth is at *A*, will come to the meridian at 10 in the forenoon when the Earth is at *B*. When the Earth comes to *C*, the point *N* will have the star on its meridian at 8 in the morning, or four hours sooner than it comes round to the Sun; for it must revolve from *N* to *n* before it has the Sun in its meridian. When the Earth comes to *D*, the point *N* will have the star on its meridian at 6 in the morning, but that point must revolve six hours more from *N* to *n*, before it has mid-day by the Sun: for now the angle *ASD* is a right angle, and so is *N D n*; that is, the Earth has advanced 90 degrees in its orbit, and must turn 90 degrees on its axis to carry the point *N* from the star to the Sun: for the star always comes to the meridian when *N m* is parallel to *R S A*; because *D S* is but a point in respect to *R S*. When the Earth is at *E*, the star comes to the meridian at 4 in the morning; at *F*, at 2 in the morning; and at *G*, the Earth having gone half round its orbit, *N* points to the star *R* at midnight, it being then directly opposite to the Sun. And therefore, by the Earth's diurnal motion, the star comes to the meridian 12 hours before the Sun. When the Earth is at *H*, the star comes to the meridian at 10 in the evening; at *I* it comes to the meridian at 8, that is, 16 hours before the Sun; at *K* 18 hours before him; at *L* 20 hours; at *M* 22; and at *A* equally with the Sun again.

A TABLE, shewing how much of the Celestial Equator passes over the Meridian in any Part of a mean SOLAR DAY; and how much the FIXED STARS gain upon the mean SOLAR TIME every Day, for a Month.

Time	Motion.			Time	Motion.			Time	Motion.				Acceleration of the Fixed Stars.		
Hours	Degrees	Minutes	Seconds	Min. — Sec. — Th.	Deg. — Min. — Sec.	Min. — Sec. — Th.	Sec. — Th. — ''''	Min. — Sec. — Th.	Deg. — Min. — Sec.	Min. — Sec. — Th.	Sec. — Th. — ''''	D.	H.	M.	S.
1	15	2	28	1	0	15	2	31	7	46	16	1	0	3	56
2	30	4	56	2	0	30	5	32	8	1	19	2	0	7	52
3	45	7	24	3	0	45	7	33	8	16	21	3	0	11	48
4	60	9	51	4	1	0	10	34	8	31	24	4	0	15	44
5	75	12	19	5	1	15	12	35	8	46	26	5	0	19	39
6	90	14	47	6	1	30	15	36	9	1	29	6	0	23	35
7	105	17	15	7	1	45	17	37	9	16	31	7	0	27	31
8	120	19	43	8	2	0	20	38	9	31	34	8	0	31	27
9	135	22	11	9	2	15	22	39	9	46	36	9	0	35	23
10	150	24	38	10	2	30	25	40	10	1	39	10	0	39	19
11	165	27	6	11	2	45	27	41	10	16	41	11	0	43	15
12	180	29	34	12	3	0	30	42	10	31	43	12	0	47	11
13	195	32	2	13	3	15	32	43	10	46	46	13	0	51	7
14	210	34	30	14	3	30	34	44	11	1	48	14	0	55	3
15	225	36	58	15	3	45	37	45	11	16	51	15	0	58	59
16	240	39	25	16	4	0	39	46	11	31	53	16	1	2	55
17	255	41	53	17	4	15	41	47	11	46	56	17	1	6	50
18	270	44	21	18	4	30	44	48	12	1	58	18	1	10	46
19	285	46	49	19	4	45	47	49	12	17	1	19	1	14	42
20	300	49	17	20	5	0	49	50	12	32	3	20	1	18	38
21	315	51	45	21	5	15	52	51	12	47	6	21	1	22	34
22	330	54	12	22	5	30	54	52	13	2	8	22	1	26	30
23	345	56	40	23	5	45	57	53	13	17	11	23	1	30	26
24	360	59	8	24	6	0	59	54	13	32	13	24	1	34	22
25	376	1	36	25	6	16	2	55	13	47	16	25	1	38	18
26	391	4	4	26	6	31	4	56	14	2	18	26	1	42	14
27	406	6	32	27	6	46	7	57	14	17	20	27	1	46	10
28	421	9	59	28	7	1	9	58	14	32	23	28	1	50	5
29	436	11	27	29	7	16	11	59	14	47	25	29	1	54	1
30	451	13	55	30	7	31	14	60	15	2	28	30	1	57	57

Thus it is plain, that an absolute turn of rth on its axis (which is always completed ny particular meridian comes to be parallel to its situation at any time of the day before) never brings the same meridian round from the Sun to the Sun again; but that the Earth requires as much more than one turn on its axis to finish a natural day, as it has gone forward in that time; which, at a mean state, is a 365th part of a circle. Hence, in 365 days, the Earth turns 366 times round its axis; and therefore, as a turn of the Earth on its axis completes a sidereal day, there must be one sidereal day more in a year than the number of solar days, be the number what it will, on the Earth, or any other planet, one turn being lost with respect to the number of solar days in a year, by the planet's going round the Sun; just as it would be lost to a traveller, who, in going round the Earth, would lose one day by following the apparent diurnal motion of the Sun; and consequently would reckon one day less at his return (let him take what time he would to go round the Earth) than those who remained [illegible] the while at the place from which he set out.

Earth on its axis never finishes a solar day.

So, if there were two Earths revolving equally on their axes, and if one remained at *A* until the other had gone round the Sun from *A* to *A* again, *that* Earth which kept its place at *A* would have its solar and sidereal days always of the same length; and so would have one solar day more than the other at its return. Hence, if the Earth turned but once round its axis in a year, and if *that* turn were made the same way as the Earth goes round the Sun, there would be continual day on one side of the Earth, and continual night on the other.

Fig. II.

223. The first part of the preceding table shews how much of the celestial equator passes over the meridian in any given part of a mean solar day, and is to be understood the same way as the table in the 220th article. The latter part, intituled,

Accelerations of the fixed Stars, affords us an easy method of knowing whether or not our clocks and watches go true: For if, through a small hole in a window-shutter, or in a thin plate of metal fixed to a window, we observe at what time any star disappears behind a chimney, or corner of a house, at a little distance; and if the same star disappear the next night 3 minutes 56 seconds sooner by the clock or watch; and on the second night, 7 minutes 52 seconds sooner; the third night 11 minutes 48 seconds sooner; and so on, every night as in the table, which shews this difference for 30 natural days, it is an infallible proof that the machine goes true; otherwise it does not go true, and must be regulated accordingly; and as the disappearing of a star is instantaneous, we may depend on this information to half a second.

To know by the stars whether a clock goes true or not.

CHAP. XIII.

Of the Equation of Time.

224. THE Earth's motion on its axis being perfectly uniform, and equal at all times of the year, the sidereal days are always precisely of an equal length; and so would the solar or natural days be, if the Earth's orbit were a perfect circle, and its axis perpendicular to its orbit. But the Earth's diurnal motion on an inclined axis, and its annual motion in an elliptic orbit, cause the Sun's apparent motion in the heavens to be unequal: for sometimes he revolves from the meridian to the meridian again in somewhat less than 24 hours, shewn by a well-regulated clock; and at other times in somewhat more; so that the time shewn by an equal-going clock and a true Sun-dial is never the same but on the 14th of *April*, the 15th of *June*, the 31st of *August*, and the 23d of *December*. The clock, if it go equably and true all the year round, will be before the

The Sun and clocks equal only on four days of the year.

Sun from the 23d of *December* till the 14th of *April*; from that time till the 16th of *June* the Sun will be before the clock; from the 15th of *June* till the 31st of *August* the clock will be again before the Sun; and from thence to the 23d of *December* the Sun will be faster than the clock.

Use of the equation-table.

225. The tables of the equation of natural days, at the end of the following chapter, shew the time that ought to be pointed out by a well regulated clock or watch, every day of the year, at the precise moment of solar noon; that is, when the Sun's centre is on the meridian, or when a true sun-dial shews it to be precisely twelve. Thus, on the 5th of *January* in leap-year, when the Sun is on the meridian, it ought to be 5 minutes 52 seconds past twelve by the clock: and on the 15th of *May*, when the Sun is on the meridian, the time by the clock should be but 56 minutes 1 second past eleven: in the former case, the clock is 5 minutes 52 seconds before the Sun; and in the latter case, the Sun is 3 minutes 59 seconds faster than the clock. But without a meridian-line, or a transit-instrument fixed in the plane of the meridian, we cannot set a sun-dial true.

How to draw a meridian-line.

226. The easiest and most expeditious way of drawing a meridian-line is this: Make four or five concentric circles, about a quarter of an inch from one another, on a flat board about a foot in breadth; and let the outmost circle be but little less than the board will contain. Fix a pin perpendicularly in the centre, and of such a length that its whole shadow may fall within the innermost circle for at least four hours in the middle of the day. The pin ought to be about an eighth part of an inch thick, and to have a round blunt point. The board being set exactly level in a place where the Sun shines, suppose from eight in the morning till four in the afternoon, about which hours the end of the shadow should fall without

all the circles; watch the times in the forenoon, when the extremity of the shortening shadow just touches the several circles, and *there* make marks. Then, in the afternoon of the same day, watch the lengthening shadow, and where its end touches the several circles in going over them, make marks also. Lastly, with a pair of compasses, find exactly the middle point between the two marks on any circle, and draw a straight line from the centre to that point: this line will be covered at noon by the shadow of a small upright wire, which should be put in the place of the pin. The reason for drawing several circles is, that in case one part of the day should prove clear, and the other part somewhat cloudy, if you miss the time when the point of the shadow should touch one circle, you may perhaps catch it in touching another. The best time for drawing a meridian line in this manner is about the summer solstice; because the Sun changes his declination slowest and his altitude fastest on the longest days.

If the casement of a window on which the Sun shines at noon be quite upright, you may draw a line along the edge of its shadow on the floor, when the shadow of the pin is exactly on the meridian line of the board: and as the motion of the shadow of the casement will be much more sensible on the floor than that of the shadow of the pin on the board, you may know to a few seconds when it touches the meridian line on the floor; and so regulate your clock for the day of observation by that line and the equation-tables above mentioned, § 225.

227. As the equation of time, or difference between the time shewn by a well regulated clock and that by a true sun-dial, depends upon two causes, namely, the obliquity of the ecliptic, and the unequal motion of the Earth in it; we shall first **Equation of natural days explained.**

explain the effects of these causes separately, and then the united effects resulting from their combination.

228. The Earth's motion on its axis being perfectly equable, or always at the same rate, and the* plane of the equator being perpendicular to its axis, it is evident that in equal times equal portions of the equator pass over the meridian; and so would equal portions of the ecliptic, if it were parallel to or coincident with the equator. But, as the ecliptic is oblique to the equator, the equable motion of the Earth carries unequal portions of the ecliptic over the meridian in equal times, the difference being proportionate to the obliquity; and as some parts of the ecliptic are much more oblique than others, those differences are unequal among themselves. Therefore if two Suns should start either from the beginning of Aries or of Libra, and continue to move through equal arcs in equal times, one in the equator, and the other in the ecliptic, the equatorial Sun would always return to the meridian in 24 hours time, as measured by a well-regulated clock; but the Sun in the ecliptic would return to the meridian sometimes sooner, and sometimes later than the equatorial Sun; and only at the same moments with him on four days of the year; namely, the 20th of *March*, when the Sun enters Aries; the 21st of *June*, when he enters Cancer; the 23d of *September*, when he enters Libra; and the 21st of *December*, when he enters Capricorn. But, as there is only one Sun, and his apparent motion is always in the ecliptic, let us henceforth call him the real Sun, and the other, which is supposed to move in the

The first part of the equation of time.

* If the Earth were cut along the equator, quite through the centre, the flat surface of this section would be the plane of the equator; as the paper contained within any circle may be justly termed the plane of that circle.

equator, the fictitious: to which last, the motion of a well-regulated clock always answers. *Plate VI.*

Let Z ♈ z ♎ be the Earth, $ZFRz$ its axis, *abcde*,&c. the equator, $ABCDE$,&c. the northern half of the ecliptic from ♈ to ♎ on the side of the globe next the eye, and $MNOP$, &c. the southern half on the opposite side from ♎ to ♈. Let the points at A, B, C, D, E, F, &c. quite round from ♈ to ♈ again, bound equal portions of the ecliptic, gone through in equal times by the real Sun; and those at a, b, c, d, e, f, &c. equal portions of the equator described in equal times by the fictitious Sun; and let Z ♈ z be the meridian. Fig. III

As the real Sun moves obliquely in the ecliptic, and the fictitious Sun directly in the equator, with respect to the meridian, a degree, or any number of degrees, between ♈ and F on the ecliptic, must be nearer the meridian Z ♈ z, than a degree, or any corresponding number of degrees, on the equator from ♈ to f; and the more so, as they are the more oblique: and therefore the true Sun comes sooner to the meridian every day while he is in the quadrant ♈ F, than the fictitious sun does in the quadrant ♈ f; for which reason, the solar noon precedes noon by the clock, until the real Sun comes to F, and the fictitious to f, which two points, being equidistant from the meridian, both suns will come to it precisely at noon by the clock.

While the real Sun describes the second quadrant of the ecliptic $FGHIKL$ from ♋ to ♎, he comes later to the meridian every day than the fictitious sun moving through the second quadrant of the equator from f to ♎; for the points at G, H, I, K, and L, being farther from the meridian than their corresponding points at g, h, i, k, and l, they must be later in coming to it: and as both suns come at the same moment to the point ♎, they come to the meridian at the moment of noon by the clock.

In departing from Libra, through the third quadrant, the real Sun going through *MNOPQ* toward ♑ at *R*, and the fictitious sun through *mnopq* toward *r*; the former comes to the meridian every day sooner than the latter, until the real Sun comes to ♑, and the fictitious to *r*, and then they both come to the meridian at the same time.

Lastly, as the real Sun moves equably through *STUVW*, from ♑ toward ♈; and the fictitious sun through *stuvw*, from *r* toward ♈, the former comes later every day to the meridian than the latter, until they both arrive at the point ♈, and then they make it noon at the same time with the clock.

229. The annexed table shews how much the Sun is faster or slower than the clock ought to be, so far as the difference depends upon the obliquity of the ecliptic; of which the signs of the first and third quadrants are at the head of the table, and their degrees at the left hand; and in these the Sun is faster than the clock: the signs of the second and fourth quadrants are at the foot of the table, and their degrees at the right hand; in all which the Sun is slower than the clock; so that entering the table with the given sign of the Sun's place at the head of the table, and the degree of his place in that sign at the left hand; or with the given sign at the foot of the table, and degree at the right hand; in the angle of meeting is the number of minutes and seconds that the Sun is faster or slower than the clock: or, in other words, the quantity of time in which the real Sun, when in that part of the ecliptic, comes sooner or later to the meridian than the fictitious sun in the equator. Thus, when the Sun's place is ♉ Taurus 12 degrees, he is 9 minutes 47 seconds faster than the clock;

A table of the equation of time depending on the Sun's place in the ecliptic.

and when his place is ♋ Cancer 18 degrees, he is 6 minutes 2 seconds slower.

Sun faster than the Clock in							
Degrees.	♈ ♎		♉ ♏		♊ ♐		1st Q. 3d Q.
	′	″	′	″	′	″	Deg.
0	0	0	8	23	8	45	30
1	0	20	8	34	8	35	29
2	0	40	8	43	8	24	28
3	1	0	8	53	8	13	27
4	1	19	9	1	8	0	26
5	1	39	9	9	7	48	25
6	1	59	9	17	7	34	24
7	2	18	9	24	7	20	23
8	2	37	9	30	7	6	22
9	2	56	9	35	6	50	21
10	3	15	9	40	6	35	20
11	3	34	9	44	6	18	19
12	3	52	9	47	6	2	18
13	4	11	9	50	5	44	17
14	4	28	9	52	5	27	16
15	4	46	9	53	5	8	15
16	5	3	9	54	4	50	14
17	5	20	9	54	4	31	13
18	5	37	9	53	4	11	12
19	5	53	9	51	3	52	11
20	6	09	9	49	3	32	10
21	6	25	9	46	3	11	9
22	6	40	9	42	2	51	8
23	6	54	9	37	2	30	7
24	7	9	9	32	2	9	6
25	7	22	9	26	1	48	5
26	7	36	9	19	1	26	4
27	7	48	9	13	1	5	3
28	8	0	9	4	0	43	2
29	8	12	8	55	0	22	1
30	8	23	8	45	0	0	0
2d Q. 4th Q	♍ ♓		♌ ♒		♋ ♑		Deg.
Sun slower than the Clock in							

This table is formed by taking the difference between the Sun's longitude and its right ascension and turning it into time.

Plate III. Fig III. 230. This part of the equation of time may perhaps be somewhat difficult to understand by a figure, because both halves of the ecliptic seem to be on the same side of the globe: but it may be made very easy to any person who has a real globe before him, by putting small patches on every tenth or fifteenth degree both of the equator and ecliptic, beginning at Aries ♈; and then turning the ball slowly round westward, he will see all the patches from Aries to Cancer come to the brazen meridian sooner than the corresponding patches on the equator; all those from Cancer to Libra will come later to the meridian than their corresponding patches on the equator; those from Libra to Capricorn sooner, and those from Capricorn to Aries later; and the patches at the beginnings of Aries, Cancer, Libra, and Capricorn, being either on or even with those on the equator, shew that the two suns either meet there, or are even with one another, and so come to the meridian at the same moment.

A machine for shewing the sidereal, the equal, and the solar time.

231. Let us suppose that there are two little balls moving equably round a celestial globe by clock-work, one always keeping in the ecliptic, and gilt with gold, to represent the real Sun; and the other keeping in the equator, and silvered, to represent the fictitious sun: and that while these balls move once round the globe according to the order of signs, the clock turns the globe 366 times round its axis westward. The stars will make 366 diurnal revolutions from the brazen meridian to it again, and the two balls representing the real and fictitious suns always going farther eastward from any given star, will come later than it to the meridian every following day: and each ball will make 365 revolutions to the meridian; coming equally to it at the beginnings of Aries, Cancer, Libra, and Capricorn; but in every other point of the ecliptic, the gilt ball will come either sooner or later to the meridian than the

silvered ball, like the patches above-mentioned. This *Plate VI.* would be a pretty way enough of shewing the reason why any given star, which, on a certain day of the year, comes to the meridian with the Sun, passes over it so much sooner every following day, as on that day twelvemonth to come to the meridian with the Sun again; and also to shew the reason why the real Sun comes to the meridian sometimes sooner, and sometimes later, than the time when it is noon by the clock; and on four days of the year, at the same time; while the fictitious sun always comes to the meridian when it is twelve at noon by the clock. This would be no difficult task for an artist to perform; for the gold ball might be carried round the ecliptic by a wire from its north pole, and the silver ball round the equator by a wire from its south pole, by means of a few wheels to each; which might be easily added to my improvement of the celestial globe, described in N° 483 of the *Philosophical Transactions;* and of which I shall give a description in the latter part of this book, from the third figure of the third plate.

232. It is plain that if the ecliptic were more obliquely posited to the equator, as the dotted circle ♈ *x* ♎, the equal divisions from ♈ to *x* would come still sooner to the meridian *Z* 0 ♈ than those marked *A*, *B*, *C*, *D*, and *E*, do: for two divisions containing 30 degrees, from ♈ to the second dot, a little short of the figure 1, come sooner to the meridian than one division containing only 15 degrees from ♈ to *A* does, as the ecliptic now stands; and those of the second quadrant from *x* to ♎ would be so much later. The third quadrant would be as the first, and the fourth as the second. And it is likewise plain, that where the ecliptic is most oblique, namely, about Aries and Libra, the difference would be greatest; and least about Cancer and Capricorn, where the obliquity is least. *Fig. IV.*

Plate VI.

The second part of the equation of time.

234. Having explained one cause of the difference of time shewn by a well-regulated clock and a true sun-dial, and considered the Sun, not the Earth, as moving in the ecliptic, we now proceed to explain the other cause of this difference, namely, the inequality of the Sun's apparent motion, § 205, which is slowest in summer, when the Sun is farthest from the Earth, and swiftest in winter when he is nearest to it. But the Earth's motion on its axis is equable all the year round, and is performed from west to east; which is the way that the Sun appears to change his place in the ecliptic.

235. If the Sun's motion were equable in the ecliptic, the whole difference between the equal time as shewn by the clock, and the unequal time as shewn by the Sun, would arise from the obliquity of the ecliptic. But the Sun's motion sometimes exceeds a degree in 24 hours, though generally it is less; and when his motion is slowest, any particular meridian will revolve sooner to him than when his motion is quickest; for it will overtake him in less time when he advances a less space than when he moves through a larger.

236. Now, if there were two suns moving in the plane of the ecliptic, so as to go round it in a year; the one describing an equal arc every 24 hours, and the other describing sometimes a less arc in 24 hours, and at other times a larger; gaining at one time of the year what it lost at the opposite; it is evident that either of these suns would come sooner or later to the meridian than the other, as it happened to be behind or before the other: and when they were both in conjunction, they would come to the meridian at the same moment.

237. As the real Sun moves unequably in the ecliptic, let us suppose a fictitious sun to move
Fig. IV. equably in a circle coincident with the plane of the ecliptic. Let *ABCD* be the ecliptic or orbit

in which the real Sun moves, and the dotted circle *a, b, c, d*, the imaginary orbit of the fictitious sun; each going round in a year according to the order of letters, or from west to east. Let *HIKL* be the Earth turning round its axis the same way every 24 hours; and suppose both suns to start from *A* and *a*, in a right line with the plane of the meridian *EH*, at the same moment: the real Sun at *A*, being then at his greatest distance from the Earth, at which time his motion is slowest; and the fictitious sun at *a*, whose motion is always equable, because his distance from the Earth is supposed to be always the same. In the time that the meridian revolves from *H* to *H* again, according to the order of the letters *HIKL*, the real Sun has moved from *A* to *F*; and the fictitious, with a quicker motion, from *a* to *f*, through a larger arc; therefore, the meridian *E H* will revolve sooner from *H* to *h* under the real Sun at *F*, than from *H* to *k* under the fictitious sun at *f*; and consequently it will then be noon by the sun-dial sooner than by the clock.

As the real Sun moves from *A* toward *C*, the swiftness of his motion increases all the way to *C*, where it is at the quickest. But notwithstanding this, the fictitious sun gains so much upon the real, soon after his departing from *A*, that the increasing velocity of the real Sun does not bring him up with the equably-moving fictitious sun till the former comes to *C*, and the latter to *c*, when each has gone half round its respective orbit; and then, being in conjunction, the meridian *E H* revolving to *E K* comes to both Suns at the same time, and therefore it is noon by them both at the same moment.

But the increased velocity of the real Sun, now being at the quickest, carries him before the fictitious one; and, therefore, the same meridian will come to the fictitious sun sooner than to the real: for while the fictitious sun moves from *c* to *g*, the real Sun moves through a greater arc from *C* to *G*: consequently the point *K* has its noon by the clock

PLATE VI. when it comes to *k*, but not its noon by the Sun till it comes to *l*. And although the velocity of the real Sun diminishes all the way from *C* to *A*, and the fictitious sun by an equable motion is still coming nearer to the real Sun, yet they are not in conjunction till the one comes to *A*, and the other to *a*; and then it is noon by them both at the same moment.

Thus it appears, that the solar noon is always later than noon by the clock while the Sun goes from *C* to *A*; sooner, while he goes from *A* to *C*, and at these two points, the Sun and clock being equal, it is noon by them both at the same moment.

Apogee, perigee, and apsides, what.

Fig. IV.

238. The point *A* is called *the Sun's apogee*, because when he is there, he is at his greatest distance from the Earth; the point *C*, his *perigee*, because when in it he is at his least distance from the Earth; and a right line, as *AEC*, drawn through the Earth's centre, from one of these points to the other, is called *the line of the apsides*.

Mean anomaly, what.

239. The distance that the Sun has gone in any time from his apogee (not the distance he has to go to it, though ever so little) is called *his mean anomaly*, and is reckoned in signs and degrees, allowing 30 degrees to a sign. Thus, when the Sun has gone 174 degrees from his apogee at *A*, he is said to be 5 signs 24 degrees from it, which is his mean anomaly; and when he has gone 355 degrees from his apogee, he is said to be 11 signs 25 degrees from it, although he be but 5 degrees short of *A*, in coming round to it again.

240. From what was said above, it appears, that when the Sun's anomaly is less than 6 signs, that is, when he is any where between *A* and *C*, in the half *ABC* of his orbit, the solar noon precedes the clock-noon; but when his anomaly is more than 6 signs, that is, when he is any where between *C* and *A*, in the half *CDA* of his orbit, the clock-noon precedes the solar. When his anomaly is 0 signs, 0 degrees, that is, when he is in his apogee at *A*;

or 6 signs, 0 degrees, which is when he is in his perigee at *C;* he comes to the meridian at the moment that the fictitious sun does, and then it is noon by them both at the same instant.

241. The following table shews the variation, or equation of time depending on the Sun's anomaly, and arising from his unequal motion in the ecliptic; as the former table, § 229, shews the variation depending on the Sun's place, and resulting from the obliquity of the ecliptic: this is to be understood the same way as the other, namely, that when the signs are at the head of the table, the degrees are at the left hand; but when the signs are at the foot of the table, the respective degrees are at the right hand; and in both cases the equation is in the angle of meeting. When both the above-mentioned equations are either faster or slower, their sum is the absolute equation of time; but when the one is faster, and the other slower, it is their difference. Thus suppose the equation depending on the Sun's place be 6 minutes 41 seconds too slow, and the equation depending on the Sun's anomaly, 4 minutes 20 seconds too slow, their sum is eleven minutes one second too slow. But if the one had been 6 minutes 41 seconds too fast, and the other 4 minutes 20 seconds too slow, their difference would have been 2 minutes 21 seconds too fast, because the greater quantity is too fast.

A Table of the equation of t me, depending on the Sun's anomaly.

	Sun faster than the Clock if his anomaly be												
	0 Signs		1		2		3		4		5		
D	M.	S	M.	S	M.	S.	M.	S	M.	S.	M.	S.	
0	0	0	3	47	6	36	7	43	6	45	3	56	30
1	0	8	3	54	6	40	7	43	6	41	3	49	29
2	0	16	4	1	6	44	7	43	6	37	3	41	28
3	0	24	4	8	6	48	7	43	6	32	3	34	27
4	0	32	4	14	6	52	7	42	6	28	3	27	26
5	0	40	4	21	6	56	7	42	6	24	3	19	25
6	0	47	4	27	6	59	7	41	6	19	3	12	24
7	0	55	4	34	7	2	7	40	6	14	3	4	23
8	1	3	4	40	7	6	7	39	6	9	2	57	22
9	1	11	4	47	7	9	7	38	6	4	2	49	21
10	1	19	4	53	7	12	7	37	5	59	2	41	20
11	1	27	4	59	7	14	7	36	5	54	2	34	19
12	1	34	5	5	7	17	7	35	5	49	2	26	18
13	1	42	5	11	7	20	7	33	5	43	2	18	17
14	1	50	5	17	7	2.	7	31	5	38	2	10	16
15	1	57	5	22	7	24	7	29	5	32	2	2	15
16	2	5	5	28	7	27	7	27	5	26	1	54	14
17	2	13	5	34	7	29	7	25	5	20	1	46	13
18	2	20	5	39	7	31	7	23	5	14	1	38	12
19	2	28	5	44	7	32	7	20	5	8	1	30	11
20	2	35	5	50	7	34	7	18	5	2	1	22	10
21	2	43	5	55	7	35	7	15	4	56	1	14	9
22	2	50	6	0	7	37	7	12	4	50	1	6	8
23	2	57	6	5	7	38	7	9	4	43	0	58	7
24	3	5	6	10	7	39	7	6	4	37	0	49	6
25	3	12	6	14	7	40	7	3	4	30	0	41	5
26	3	19	6	19	7	41	7	0	4	23	0	33	4
27	3	26	6	24	7	41	6	56	4	17	0	25	3
28	3	33	6	28	7	42	6	53	4	10	0	17	2
29	3	40	6	32	7	42	6	49	4	3	0	8	1
30	3	47	6	36	7	43	6	45	3	56	0	0	0
	11 Signs		10		9		8		7		6		D.

This table is formed by turning the equation of the Sun's centre (see p. 344) into time.

242. The obliquity of the ecliptic to the equator, which is the first mentioned cause of the equation of time, would make the Sun and clock agree on

four days of the year; namely, when the Sun enters Aries, Cancer, Libra, and Capricorn: but the other cause, now explained, would make the Sun and clock equal only twice in a year; that is, when the Sun is in his apogee,and in his perigee. Consequently, when these two points fall in the beginnings of Cancer and Capricorn, or of Aries and Libra, they concur in making the Sun and clock equal in these points. But the apogee at present is in the 9th degree of Cancer, and the perigee in the 9th degree of Capricorn; and therefore the Sun and clock cannot be equal about the beginnings of these signs, nor at any time of the year, except when the swiftness or slowness of the equation resulting from one cause just balances the slowness or swiftness arising from the other.

243. The second table in the following chapter shews the Sun's place in the ecliptic at the noon of every day by the clock, for the second year after leap-year; and also the Sun's anomaly to the nearest degree, neglecting the odd minutes of that degree. Its use is only to assist in the method of making a general equation-table from the two forementioned tables of equation depending on the Sun's place and anomaly, § 229, 241; concerning which method we shall give a few examples presently. The next tables which follow them are made from those two; and shew the absolute equation of time resulting from the combination of both its causes; in which the minutes as well as degrees, both of the Sun's place and anomaly, are considered. The use of these tables is already explained, § 225: and they serve for every day in leap-year, and the first, second, and third years after: For on most of the same days of all these years the equation differs, because of the odd six hours more than the 365 days of which the year consists.

Examples for making equation-tables.

EXAMPLE I. On the 14th of *April*, the Sun is in the 25th degree of ♈ Aries and his anomaly is 9 signs 15 degrees; the equation resulting from the

former is 7 minutes 22 seconds of time too fast, § 229; and from the latter, 7 minutes 24 seconds too slow, § 241; the difference is 2 seconds that the Sun is too slow at the noon of that day, taking it in gross for the degrees of the Sun's place and anomaly, without making proportionable allowance for the odd minutes. Hence at noon, the swiftness of the one equation balancing so nearly the slowness of the other, makes the Sun and clock equal on some part of that day.

Example II. On the 16th of *June*, the Sun is in the 25th degree of ♊ Gemini, and his anomaly is 11 signs 16 degrees; the equation arising from the former is 1 minute 48 seconds too fast; and from the latter 1 minute 50 seconds too slow; which balancing one another at noon to 2 seconds, the Sun and clock are again equal on that day.

Example III. On the 31st of *August*, the Sun's place is 8 degrees 11 minutes of ♍ Virgo (which we call the 8th degree, as it is so near), and his anomaly is 1 sign 29 degrees; the equation arising from the former is 6 minutes 40 seconds too slow; and from the latter, 6 minutes 32 seconds too fast; the difference being only 8 seconds too slow at noon, and decreasing toward an equality, will make the Sun and clock equal in the evening of that day.

Example IV. On the 23d of *December*, the Sun's place is 1 degree 58 minutes (call it 2 degrees of ♑ Capricorn), and his anomaly is 5 signs 23 degrees; the equation for the former is 43 seconds too slow, and for the latter 58 seconds too fast; the difference is 15 seconds too fast at noon; which decreasing will come to an equality, and so make the Sun and clock equal in the evening of that day.

And thus we find, that on some part of each of the above-mentioned four days, the Sun and clock

are equal; but if we work examples for all other days of the year, we shall find them different. And,

244. On those days which are equidistant from any equinox or solstice, we do not find that the equation is as much too fast or too slow on the one side, as it is too slow or too fast on the other. The reason is, that the line of the apsides, § 238, does not, at present, fall either into the equinoctial or the solstitial points, § 242. Remark.

245. The four following equation-tables, for leap-year, and the first, second, and third years after, would serve for ever, if the Sun's place and anomaly were always the same on every given day of the year, as on the same day four years before or after. But since that is not the case, no general equation-tables can be so constructed as to be perpetual. The reason why equation-tables are but temporary.

CHAP. XIV.

Of the Precession of the Equinoxes.

246. IT has been already observed, § 116, that by the Earth's motion on its axis, there is more matter accumulated all around the equatorial parts, than any where else on the Earth.

The Sun and Moon, by attracting this redundancy of matter, bring the equator sooner under them in every return towards it, than if there was no such accumulation. Therefore, if the Sun sets out from any star, or other fixed point in the heavens, the moment when he is departing from the equinoctial, or from either tropic; he will come to the same equinox or tropic again 20 min. 17¼ sec. of time, or 50 seconds of a degree, before he completes his course, so as to arrive at the same fixed star or point from whence he set out. For the equinoctial points recede 50 seconds of a degree westward every year, contrary to the Sun's annual progressive motion.

PLATE VI. When the Sun arrives at the same * equinoctial or solstitial point, he finishes what we call the *tropical year;* which, by observation, is found to contain 365 days 5 hours 48 minutes 57 seconds: and when he arrives at the same fixed star again, as seen from the Earth, he completes the *sidereal year,* which contains 365 days 6 hours 9 minutes 14½ seconds. The *sidereal year* is therefore 20 minutes 17½ seconds longer than the solar or tropical year, and 9 minutes 14½ seconds longer than the Julian or civil year, which we state at 365 days 6 hours: so that the civil year is almost a mean betwixt the sidereal and the tropical.

247. As the Sun describes the whole ecliptic, or 360 degrees, in a tropical year, he moves 59′ 8″ of a degree every day at a mean rate: and consequently 50″ of a degree in 20 minutes 17½ seconds of time: therefore he will arrive at the same equinox or solstice when he is 50″ of a degree short of the same star or fixed point in the heavens from which he set out the year before. So that, with respect to the fixed stars, the Sun and equinoctial points fall back (as it were) 30 degrees in 2160 years, which will make the stars appear to have gone 30 deg. forward, with respect to the signs of the ecliptic in that time: for the same signs always keep in the same points of the ecliptic, without regard to the constellations.

Fig. IV To explain this by a figure, let the Sun be in conjunction with a fixed star at *S*, suppose in the 30th degree of ♉, on the 21st day of *May* 1756. Then making 2160 revolutions through the ecliptic *VIWX*,

* The two opposite points in which the ecliptic crosses the equinoctial, are called *the equinoctial points*: and the two points where the ecliptic touches the tropics (which are likewise opposite, and 90 degrees from the former) are called *the solstitial points.*

A TABLE *shewing the Precession of the Equinoctial Points in the Heavens, both in Motion and Time; and the Anticipation of the Equinoxes on the Earth.*

Julian years.	Precession of the Equinoctial Points in the Heavens.								Anticipation of the Equinoxes on the Earth.			
	Motion.				Time.							
	s.	°	′	″	Days	H.	M.	S.	D.	H.	M.	S.
1	0	0	0	50	0	0	20	17½	0	0	11	3
2	0	0	1	40	0	0	40	35	0	0	22	6
3	0	0	2	30	0	1	0	52½	0	0	33	9
4	0	0	3	20	0	1	21	10	0	0	44	12
5	0	0	4	10	0	1	41	27½	0	0	55	15
6	0	0	5	0	0	2	1	45	0	1	6	18
7	0	0	5	50	0	2	22	2½	0	1	17	21
8	0	0	6	40	0	2	42	20	0	1	28	24
9	0	0	7	30	0	3	2	37½	0	1	39	27
10	0	0	8	20	0	3	22	55	0	1	50	30
20	0	0	16	40	0	6	45	50	0	3	41	0
30	0	0	25	0	0	10	[illegible]	45	0	5	31	30
40	0	0	33	20	0	13	31	40	0	7	22	0
50	0	0	41	40	0	16	54	35	0	9	12	30
60	0	[illegible]	50	0	0	[illegible]	17	30	0	11	8	0
70	0	0	58	20	0	23	[illegible]	25	0	12	53	30
80	0	1	6	40	1	3	3	20	0	14	44	0
90	0	1	15	0	1	6	20	15	0	16	34	30
100	0	1	23	20	1	9	49	10	0	18	25	0
200	0	2	46	40	2	19	38	20	1	12	50	0
300	0	[illegible]	10	0	4	5	27	30	[illegible]	7	15	0
400	0	5	33	20	5	15	16	40	3	1	40	0
500	0	6	56	40	7	1	[illegible]	50	3	20	5	0
600	0	8	20	0	8	10	55	0	4	14	30	0
700	0	9	43	20	9	20	44	10	5	8	55	0
800	0	11	6	40	11	6	33	20	6	3	20	0
900	0	12	30	0	12	16	22	30	6	21	45	0
1000	0	13	53	20	14	2	11	40	7	16	10	0
2000	0	27	40	40	28	4	23	20	15	8	20	0
3000	1	11	40	0	42	6	35	0	23	0	30	0
4000	1	25	33	20	56	8	40	40	30	10	40	0
5000	2	9	20	40	70	10	[illegible]	20	38	8	50	[illegible]
6000	2	23	20	0	[illegible]	13	10	0	46	1	0	
7000	3	[illegible]	13	20	[illegible]	15	21	40	53	17	[illegible]	
8000	3	21	6	40	112	17	33	20	61	[illegible]		
9000	4	5	0	0	126	19	45	[illegible]	69			
10000	[illegible]	18	53	20	140	21	56	40	76			
20000	9	7	[illegible]	40	281	19	53	[illegible]	[illegible]	1.		
25920	12	0	0	0	365	6	0	0	[illegible]	21		

at the end of so many sidereal years, he will be found again at *S*: but at the end of so many Julian years, he will be found at *M*, short of *S*, and at the end of so many tropical years, he will be found short of *M*, in the 30th degree of Taurus at *T*, which has receded back from *S* to *T* in that time, by the precession of the equinoctial points ♈ *Aries* and ♎ *Libra*.

The arc *ST* will be equal to the amount of the precession of the equinox in 2160 years at the rate of 50″ of a degree, or 20 min. $17\frac{1}{2}$ sec. of time annually: this, in so many years, makes 30 days $10\frac{1}{2}$ hours: which is the difference between 2160 sidereal and tropical years. And the arc *MT* will be equal to the space moved through by the Sun in 2160 times 11 min. 3 sec. or 16 days 13 hours 48 minutes, which is the difference between 2160 Julian and tropical years.

248. From the shifting of the equinoctial points, and with them all the signs of the ecliptic, it follows that those stars which in the infancy of astronomy were in *Aries* are now got into *Taurus*: those of *Taurus* into *Gemini*, &c. Hence likewise it is, that the stars which rose or set at any particular season of the year, in the times of Hesiod, Eudoxus, Virgil, Pliny, &c. by no means answer at this time to their descriptions. The preceding table shews the quantity of this shifting both in the heavens and on the Earth, for any number of years to 25,920; which completes the grand celestial period: within which any number and its quantity is easily found, as in the following example, for 5763 years; which at the autumnal equinox, *A. D.* 1756, is thought to be the age of the world. So that with regard to the fixed stars, the equinoctial points in the heavens have receded $2^s\ 20^\circ\ 2'\ 30''$ since the creation; which is as much as the Sun moves in in $81^d\ 5^h\ 0^m\ 52^s$. And since that time, or in 5763 years, the equinoxes with us have fallen back $44^d\ 5^h\ 21^m\ 9^s$; hence, reckoning from the time of the *Julian* equinox, *A. D.* 1756, *viz.* *Sept.* 11th, it

appears that the autumnal equinox at the creation was on the 25th of *October*.

Julian years.	Precession of the Equinoctial Points in the Heavens.								Anticipation of the Equinoxes on the Earth.			
	Motion.				Time.							
	s	°	′	″	D.	H.	M.	S.	D.	H.	M.	S.
5000	2	9	26	40	70	10	58	20	38	8	50	0
700	0	9	43	20	9	20	44	10	5	8	55	0
60	0	0	50	0	0	20	17	30	0	11	3	0
3	0	0	2	30	0	1	0	52	0	0	33	9
5763	2	20	2	30	81	5	0	52	44	5	21	9

The anticipation of the equinoxes and seasons.

249. The anticipation of the equinoxes, and consequently of the seasons, is by no means owing to the precession of the equinoctial and solstitial points in the heavens (which can only affect the apparent motions, places and declinations of the fixed stars) but to the difference between the civil and solar year, which is 11 minutes 3 seconds; the civil year containing 365 days 6 hours, and the solar year 365 days 5 hours 48 minutes 57 seconds. The next following table, page 189, shews the length, and consequently the difference of any number of sidereal, civil and solar years, from 1 to 10,000.

The reason for altering the style.

250. The above 11 minutes 3 seconds, by which the civil or Julian year, exceeds the solar, amounts to 11 days in 1433 years: and so much our seasons have fallen back with respect to the days of the months, since the time of the *Nicene* council in *A. D.* 325; and therefore, in order to bring back all the fasts and festivals to the days then settled, it was requisite to suppres 11 nominal days. And that the same seasons might be kept to the same times of the year for the future, to leave out the Bissex-

PLATE VI. tile-day in *February* at the end of every century of years where the significant figures are not divisible by 4; reckoning them only common years, as the 17th, 18th, and 19th centuries, *viz.* the years 1700, 1800, 1900, &c. because a day intercalated every fourth year was too much, and retaining the Bissextile-day at the end of those centuries of years which are divisible by 4, as the 16th, 20th and 24th centuries; *viz.* the years 1600, 2000, 2400, &c. Otherwise, in length of time, the seasons would be quite reversed with regard to the months of the year; though it would have required near 23,783 years to have brought about such a total change. If the Earth had made exactly $365\frac{1}{4}$ diurnal rotations on its axis, while it revolved from any equinoctial or solstitial point to the same again, the civil and solar years would always have kept pace together, and the style would never have required any alteration.

The precession of the equinoctial points. 251. Having already mentioned the cause of the precession of the equinoctial points in the heavens, § 246, which occasions a slow deviation of the Earth's axis from its parallelism, and thereby a change of the declination of the stars from the equator, together with a slow apparent motion of the stars forward with respect to the signs of the ecliptic, we shall now explain the phenomena by a diagram.

Fig. VI. Let *NZSVL* be the Earth, *SONA* its axis produced to the starry heavens, and terminating in *A*, the present north pole of the heavens, which is vertical to *N*, the north pole of the Earth. Let *EOQ* be the equator, *T* ♋ *Z* the tropic of Cancer, and *VT* ♑ the tropic of Capricorn: *VOZ* the ecliptic, and *BO* its axis, both which are immoveable among the stars. But as * the equinoctial points recede in

* The equinoctial circle intercepts the ecliptic in two opposite points; namely, the first points of the signs *Aries* and *Libra*. They are called the equinoctial points, because when the Sun is in either

the ecliptic, the Earth's axis *SON* is in motion upon the Earth's centre *O*, in such a manner as to describe the double cone *NOn* and *Sos*, round the axis of the ecliptic, *BO*, in the time that the equinoctial points move quite round the ecliptic, which is 25,920 years; and in that length of time the north pole of the Earth's axis produced, describes the circle *ABCDA*, in the starry heavens, round the pole of the ecliptic, which keeps immoveable in the centre of that circle, the Earth's axis being $23\frac{1}{2}$ degrees inclined to the axis of the ecliptic, the circle *ABC D A*, described by the north pole of the Earth's axis produced to *A*, is 47 degrees in diameter, or double the inclination of the Earth's axis. In consequence of this motion, the point *A*, which at present is the north pole of the heavens, and near to a star of the second magnitude in the tail of the constellation called *the Little Bear*, must be deserted by the Earth's axis; which moving backward a degree every 72 years, will be directed toward the star or point *B* in 6480 years from this time; and in twice that time, or 12960 years, it will be directed toward the star or point *C*: which will then be the north pole of the heavens, although it is at present $8\frac{1}{2}$ degrees south of the zenith of *London L*. The present position of the equator *EOQ* will then be changed into *eOq*, the tropic of Cancer *T* ♋ *Z* into *Vt* ♋ and the tropic of Capricorn *VT* ♑ into *t* ♑ *Z*; as is evident by the figure; and the Sun, when in that part of the heavens, where he is now over the terrestrial tropic of Capricorn, and makes the shortest days and longest nights in the northern hemisphere, will then be over the terrestrial tropic of Cancer, and make the days longest and nights shortest. And it will require 12,960 years more, or 25,920 from the pre-

of them, he is directly over the terrestrial equator: and then the days and nights are equal.

sent time, to bring the north pole N quite round, so as to be directed toward that point of the heavens which is vertical to it at present. And then, and not till then, the same stars, which at present describe the equator, tropics, polar circles, &c. by the Earth's diurnal motion, will describe them over again.

TABLE shewing the Time contained in any Number of Sidereal, Julian, and Solar Years, from 1 *to* 10000.

	Sidereal Years.				Julian Years.		Solar Years.			
Years.	Days.	H	M.	S.	Days.	H.	Days.	H.	M.	S.
1	365	6	9	14½	365	6	365	5	48	57
2	730	12	18	29	730	12	730	11	37	54
3	1095	18	27	43½	1095	18	1095	17	26	51
4	1461	0	36	58	1461	0	1460	23	15	48
5	1826	6	46	12½	1826	6	1826	5	4	45
6	2191	12	55	27	2191	12	2191	10	53	42
7	2556	19	5	41½	2556	18	2556	16	42	39
8	2922	1	13	56	2922	0	2921	22	31	36
9	3287	7	23	10½	3287	6	3287	4	20	33
10	3652	13	32	25	3652	12	3652	10	9	30
20	7305	3	4	50	7305	0	7304	20	19	0
30	10957	16	37	15	10957	12	10957	6	28	30
40	14610	6	9	40	14610	0	14609	16	38	0
50	18262	19	42	5	18262	12	18262	2	47	0
60	21915	9	14	30	21915	6	21914	12	57	0
70	25567	22	46	55	25567	12	25566	2	6	30
80	29220	12	19	20	29220	0	29219	9	16	0
90	32873	1	51	45	32872	12	32871	19	25	30
100	36525	15	24	10	36525		36524	5	35	
200	73051	6	48	20	73050		73048	11	10	
300	109576	22	12	30	109575		109572	16	45	
400	146102	13	36	40	146100		146096	22	20	
500	182628	5	0	50	182625		182621	3	55	
600	219153	20	25		219150		219145	9	30	
700	255679	11	49	10	255675		255669	15	5	
800	292205	3	13	20	292200		292193	20	40	
900	228730	18	37	30	328725		328718	2	15	
1000	365256	10	1	40	365250		365242	7	50	
2000	730512	20	3	20	730500		730484	15	40	
3000	1095769	6	5		1095750		1095720	23	30	
4000	1461025	16	6	40	1461000		1460969	7	20	
5000	1826282	2	8	20	1826250		1826211	15	10	
6000	2191538	12	10		2191500		2191453	23	0	
7000	2556794	22	11	40	2556750		2556696	6	50	
8000	2952051	8	13	20	2922000		2921938	14	40	
9000	3287037	18	15		3287250		3287180	22	30	
10000	3652564	4	16	40	3652500		3652423	6	20	

A TABLE shewing the Sun's true Place, and Distance from its Apogee, for the second Year after Leap-Year.

Days.	January.		February.		March.		April.	
	Sun's Place.	Sun's Anom.	Sun's Place.	Sun's Anom.	Sun's Place.	Sun's Anom.	Sun's Place.	Sun's Anom.
	D. M.	D. M.	D. M.	D. M.	D. M.	D. M.	D. M.	D. M.
1	11 ♑ 23	6 2	12 ♒ 56	7 4	11 ♓ 10	8 2	11 ♈ 57	9 3
2	12 24	6 3	13 57	7 5	12 10	[illegible] 3	12 56	9 4
3	13 25	6 [illegible]	14 58	7 6	13 10	8 4	13 55	[illegible] 5
4	14 27	6 5	15 58	7 7	14 10	8 5	.4 54	9 6
5	15 28	6 6	16 59	7 8	15 10	8 6	15 53	9 7
6	16 29	6 7	18 00	7 9	16 10	8 7	16 52	9 8
7	17 30	6 8	19 01	7 10	17 10	8 8	17 51	9 8
8	18 31	6 9	20 01	7 11	18 10	8 9	18 49	9 9
9	19 32	6 10	21 02	7 12	19 09	8 10	19 48	9 10
10	20 34	6 11	22 03	7 13	20 09	8 11	20 47	[illegible] 11
11	21 35	6 12	23 03	[illegible] 14	31 09	8 12	21 46	9 12
12	22 35	6 13	24 04	7 15	22 09	8 13	22 44	9 13
13	23 37	6 14	25 04	7 16	23 09	8 14	23 43	9 14
14	24 38	6 15	26 05	7 17	24 [illegible]	8 15	24 42	[illegible] 15
15	25 39	6 16	27 06	7 18	25 08	8 16	25 40	9 16
16	26 40	6 17	28 06	7 19	26 08	8 17	26 39	9 17
17	27 42	6 18	29 07	7 20	27 07	8 18	27 38	9 18
18	28 43	6 19	♓ 07	7 21	28 07	8 19	28 36	9 19
19	29 44	6 20	1 07	7 22	29 06	[illegible] 20	29 35	9 20
20	♒ 45	6 21	2 08	7 23	♈ 06	8 21	♉ 33	9 21
21	1 46	6 22	3 08	7 24	1 05	8 22	1 32	9 22
22	2 47	6 23	4 08	7 25	2 05	8 23	2 30	9 23
23	3 48	6 24	5 09	7 26	3 04	8 24	3 28	9 24
24	4 49	6 25	6 09	7 27	4 03	8 25	4 27	9 25
25	5 50	6 26	7 09	7 28	5 03	8 26	5 25	9 26
26	6 51	6 28	8 09	7 29	6 02	8 27	6 23	9 27
27	7 52	6 29	9 10	8 [illegible]	7 01	8 28	7 21	9 28
28	8 53	7 0	10 10	8 1	8 00	8 29	8 20	9 29
29	9 53	7 1			9 00	9 0	9 18	10 0
30	10 54	7 2			9 59	[illegible] 1	10 16	10 1
31	11 55	7 3			10 58	9 2		

A TABLE shewing the Sun's true Place, and Distance from its Apogee, for the second Year after Leap-Year.

Days.	May. Sun's Place. D.	M.	Sun's Anom. S.	D.	June. Sun's Place. D.	M.	Sun's Anom. S.	D.	July. Sun's Place. D.	M.	Sun's Anom. S.	D.	August. Sun's Place. D.	M.	Sun's Anom. S.	D.
1	11 ♉	14	10	2	11 ♊	04	11	2	9 ♋	42	0	0	9 ♌	18	1	0
2	12	12	10	3	12	01	11	3	10	39	0	1	10	16	1	1
3	13	10	10	4	12	59	11	4	11	37	0	2	11	13	1	2
4	14	08	10	5	13	56	11	5	12	34	0	3	12	11	1	3
5	15	06	10	6	14	53	11	6	13	31	0	4	13	08	1	4
6	16	04	10	7	15	51	11	6	14	28	0	5	14	06	1	5
7	17	02	10	8	16	48	11	7	15	25	0	6	15	03	1	6
8	18	00	10	9	17	46	11	8	16	23	0	7	16	01	1	7
9	18	58	10	10	18	43	11	9	17	20	0	8	16	58	1	8
10	19	56	10	11	19	40	11	10	18	17	0	9	17	56	1	9
11	20	54	10	12	20	38	11	11	19	14	0	10	18	54	1	10
12	21	52	10	12	21	35	11	12	20	12	0	11	19	51	1	10
13	22	49	10	13	22	32	11	13	21	09	0	12	20	49	1	11
14	23	47	10	14	23	30	11	14	22	06	0	13	21	47	1	12
15	24	45	10	15	24	27	11	15	23	03	0	14	22	44	1	13
16	25	43	10	16	25	24	11	16	24	01	0	15	23	42	1	14
17	26	41	10	17	26	21	11	17	24	58	0	16	24	40	1	15
18	27	38	10	18	27	19	11	18	25	55	0	17	25	38	1	16
19	28	36	10	19	28	16	11	19	26	53	0	18	26	36	1	17
20	29	34	10	20	29	13	11	20	27	50	0	18	27	33	1	18
21	♊	31	10	21	♋	10	11	21	28	47	0	19	28	31	1	19
22	1	29	10	22	1	08	11	22	29	44	0	20	29	29	1	20
23	2	26	10	23	2	05	11	23	♌	42	0	21	♍	27	1	21
24	3	24	10	24	3	02	11	24	1	39	0	22	1	25	1	22
25	4	22	10	25	3	59	11	25	2	36	0	23	2	23	1	23
26	5	19	10	26	4	56	11	26	3	34	0	24	3	21	1	24
27	6	17	10	27	5	53	11	27	4	31	0	25	4	19	1	25
28	7	14	10	28	6	51	11	27	5	28	0	26	5	17	1	26
29	8	12	10	29	7	48	11	28	6	26	0	27	6	15	1	27
30	9	09	11	0	8	45	11	29	7	23	0	28	7	13	1	28
31	10	06	11	1					8	21	0	29	8	11	1	29

A TABLE shewing the Sun's true Place, and Distance from its Apogee, for the second Year after Leap-Year.

Days.	September.				October.				November				December			
	Sun's Place		Sun's Anom.		Sun's Place.		Sun's Anom.		Sun's Place		Sun's Anom.		Sun's Place		Sun's Anom.	
	D.	M.	S.	D.	D.	M.	S.	D.	D.	M.	S.	D.	D.	M.	S.	D.
1	9 ♍	09	2	0	8 ♎	28	2	29	9 ♏	17	4	0	9 ♐	34	[illegible]	0
2	10	07	2	1	9	27	3	0	10	17	4	1	10	35	5	1
3	11	05	2	2	10	26	3	1	11	17	4	2	11	36	5	2
4	12	04	2	3	11	25	3	2	12	18	4	3	12	37	5	3
5	13	02	2	4	12	25	3	3	13	18	4	4	13	38	5	4
6	14	00	2	5	13	24	3	4	14	18	4	5	14	39	5	5
7	14	59	2	6	14	23	3	5	15	19	4	6	15	40	5	6
8	15	57	2	7	15	23	3	6	16	19	4	7	16	41	5	7
9	16	55	2	8	16	22	3	7	17	19	4	8	17	42	5	8
10	17	54	2	9	17	21	3	8	18	20	4	9	18	43	5	9
11	18	52	2	9	18	21	3	9	19	20	4	10	19	44	5	10
12	19	51	2	10	19	20	3	10	20	21	4	11	20	45	5	11
13	20	49	2	11	20	20	3	11	21	22	4	12	21	46	5	12
14	21	48	2	12	21	20	3	12	22	23	4	13	22	47	5	13
15	22	46	2	13	22	19	3	13	23	22	4	14	23	49	5	14
16	23	45	2	14	23	19	3	14	24	23	4	15	24	50	5	15
17	24	44	2	15	24	18	3	15	25	23	4	16	25	51	5	16
18	25	42	2	16	25	18	3	16	26	24	4	17	26	52	5	17
19	26	41	2	17	26	18	3	17	27	25	4	18	27	55	5	19
20	27	40	2	18	27	18	3	18	28	25	4	19	28	54	5	20
21	28	39	2	19	28	17	3	19	29	26	4	20	29	55	5	21
22	29	37	2	20	29	17	3	20	♐	27	4	21	♑	56	5	22
23	♎	36	2	21	♏	17	3	21	1	27	4	22	1	58	5	23
24	1	35	2	22	1	17	3	22	2	28	4	23	2	59	5	24
25	2	34	2	23	2	17	3	23	3	29	4	24	4	00	5	25
26	3	33	2	24	3	17	3	24	4	30	4	25	5	01	5	26
27	4	32	2	25	4	17	[illegible]	25	5	30	4	26	6	02	5	27
28	5	31	2	26	5	17	3	26	6	31	4	27	7	03	5	28
29	6	30	2	27	6	17	3	27	7	32	4	28	8	05	5	29
30	7	29	2	28	7	17	3	28	8	33	4	29	9	06	6	0
31					8	17	3	29					10	07	6	1

TABLES

OF THE

EQUATION OF TIME,

FOR

LEAP-YEARS AND COMMON YEARS;

Shewing what Time it ought to be by the Clock when the Sun's Centre is on the Meridian.

A TABLE shewing what Time it ought to be by the Clock when the Sun's Centre is on the Meridian.

The Bissextile or Leap-Year.

Days.	January.			February.			March.			April.		
	H.	M.	S.	H.	M.	S.	H.	M.	S	H.	M.	S.
1	XII	4	20	XII	14	3	XII	12	30	XII	3	42
2		4	30		14	10		12	17		3	24
3		4	58		14	17		12	4		3	6
4		5	25		14	22		11	50		2	48
5		5	52		14	27		11	35		2	30
6	XII	6	19	XII	14	31	XII	11	21	XII	2	13
7		6	45		14	34		11	6		1	55
8		7	10		14	37		10	50		1	38
9		7	35		14	38		10	34		1	21
10		8	0		14	39		10	18		1	4
11	XII	8	24	XII	14	39	XII	10	2	XII	0	48
12		8	47		14	38		9	45		0	32
13		9	10		14	37		9	28		0	17
14		9	32		14	35		9	11		0	1
15		9	53		14	32		8	54	XI	59	47
16	XII	10	14	XII	14	28	XII	8	36	XI	59	32
17		10	34		14	24		8	18		59	18
18		10	53		14	19		8	0		59	4
19		11	12		14	13		7	42		58	51
20		11	30		14	7		7	24		58	38
21	XII	11	47	XII	14	0	XII	7	6	XI	58	26
22		12	3		13	52		6	47		58	14
23		12	19		13	44		6	29		58	2
24		12	34		13	35		6	10		57	51
25		12	48		13	26		5	52		57	41
26	XII	13	0	XII	13	16	XII	5	33	XI	57	31
27		13	13		13	5		5	15		57	21
28		13	25		12	54		4	56		57	12
29		13	36		12	42		4	37		57	4
30		13	45					4	19		56	55
31		13	54					4	0			

A TABLE shewing what Time it ought to be by the Clock when the Sun's Centre is on the Meridian.

The Bissextile, or Leap-Year.

Days	May.			June.			July.			August.		
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.
1	XI	56	48	XI	57	30	XII	3	29	XII	5	51
2		56	41		57	40		3	40		5	47
3		56	34		57	49		3	51		5	42
4		56	28		57	59		4	02		5	36
5		56	23		58	10		4	12		5	30
6	XI	56	18	XI	58	20	XII	4	22	XII	5	23
7		56	14		58	31		4	31		5	16
8		56	10		58	42		4	40		5	2
9		56	7		58	54		4	49		5	0
10		56	5		59	6		4	57		4	51
11	XI	56	3	XI	59	18	XII	5	5	XII	4	41
12		56	1		59	30		5	13		4	31
13		56	0		59	42		5	20		4	21
14		56	0		59	55		5	26		4	10
15		56	01	XII	0	8		5	32		3	58
16	XI	56	2	XII	0	20	XII	5	38	XII	3	46
17		56	4		0	33		5	43		3	33
18		56	6		0	46		5	48		3	20
19		56	9		0	59		5	52		3	7
20		56	12		1	13		5	56		2	52
21	XI	56	16	XII	1	26	XII	5	59	XII	2	38
22		56	20		1	39		6	1		2	23
23		56	25		1	52		6	3		2	7
24		56	31		2	4		6	4		1	52
25		56	36		2	17		6	4		1	35
26	XI	56	43	XII	2	30	XII	6	4	XII	1	18
27		56	50		2	42		6	4		1	1
28		56	57		2	54		6	2		0	44
29		57	5		3	6		6	0		0	26
30		57	13		3	18		5	58		0	8
31		57	21					5	55	XI	59	40

A TABLE shewing what Time it ought to be by the Clock when the Sun's Centre is on the Meridian.

The Bissextile, or Leap-Year.

Days.	September.			October.			November.			December.		
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.
1	XI	59	30	XI	49	22	XI	43	45	XI	49	43
2		59	11		49	3		43	45		50	7
3		58	52		48	45		43	45		50	31
4		58	32		48	27		43	47		50	56
5		58	12		48	9		43	49		51	21
6	XI	57	52	XI	47	52	XI	43	53	XI	51	47
7		57	32		47	36		43	57		52	13
8		57	12		47	19		44	2		52	40
9		56	51		47	4		44	8		53	8
10		56	30		46	48		44	14		53	35
11	XI	56	10	XI	46	33	XI	44	22	XI	54	3
12		55	49		46	19		44	30		54	32
13		55	28		46	6		44	[illegible]		55	01
14		55	7		45	52		44	50		55	30
15		54	46		45	40		45	1		56	0
16	XI	54	25	XI	45	28	XI	45	13	XI	56	29
17		54	5		45	16		45	25		56	59
18		53	44		45	6		45	39		57	29
19		53	23		44	55		45	53		57	59
20		53	2		44	46		46	8		58	29
21	XI	52	41	XI	44	37	XI	46	24	XI	58	59
22		52	21		44	29		46	41		59	29
23		52	0		44	21		46	58		59	59
24		51	40		44	14		47	16	XII	0	29
25		51	19		44	8		47	35		0	59
26	XI	50	59	XI	44	2	XI	47	55	XII	1	29
27		50	39		43	57		48	15		1	58
28		50	20		43	53		48	36		2	27
29		50	0		43	50		48	58		2	56
30		49	41		43	48		49	20		3	25
31					43	46					3	54

A TABLE shewing what Time it ought to be by the Clock when the Sun's Centre is on the Meridian.

The first Year after Leap-Year.

Days.	January.			February.			March.			April.		
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.
1	XII	4	23	XII	14	9	XII	12	33	XII	3	47
2		4	51		14	16		12	20		3	39
3		5	19		14	21		12	7		3	10
4		5	46		14	27		11	54		2	52
5		6	13		14	31		11	40		2	35
6	XII	6	39	XII	14	34	XII	11	25	XII	2	17
7		7	4		14	37		11	10		2	0
8		7	30		14	39		10	55		1	43
9		7	54		14	40		10	39		1	25
10		8	18		14	40		10	23		1	9
11	XII	8	42	XII	14	39	XII	10	7	XII	0	53
12		9	4		14	38		9	50		0	36
13		9	26		14	36		9	33		0	20
14		9	48		14	33		9	16		0	5
15		10	9		14	30		8	58	XI	59	50
16	XII	10	29	XII	14	25	XII	8	41	XI	59	35
17		10	48		14	20		8	23		59	21
18		11	7		14	15		8	5		59	7
19		11	25		14	9		7	47		58	54
20		11	42		14	2		7	29		58	41
21	XII	11	59	XII	13	54	XII	7	10	XI	58	28
22		12	15		13	46		6	52		58	16
23		12	30		13	37		6	33		58	4
24		12	44		13	28		6	15		57	53
25		12	58		13	18		5	56		57	43
26	XII	13	10	XII	13	8	XII	5	38	XI	57	32
27		13	22		12	57		5	19		57	23
28		13	33		12	45		5	1		57	14
29		13	43					4	42		57	5
30		13	53					4	23		56	
31		14	1					4	5			

A TABLE shewing what Time it ought to be by the Clock when the Sun's Centre is on the Meridian.

The first Year after Leap-Year.

Days	May.			June.			July.			August.		
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.
1	XI	56	49	XI	57	27	XII	3	26	XII	5	52
2		56	42		57	36		3	37		5	48
3		56	35		57	46		3	48		5	43
4		56	29		57	56		3	58		5	38
5		56	24		58	6		4	9		5	32
6	XI	56	19	XI	58	17	XII	4	19	XII	5	25
7		56	14		58	27		4	28		5	18
8		56	11		58	38		4	37		5	10
9		56	7		58	50		4	46		5	2
10		56	5		59	2		4	55		4	53
11	XI	56	2	XI	59	14	XII	5	3	XII	4	44
12		56	1		59	26		5	10		4	34
13		56	0		59	38		5	17		4	24
14		56	0		59	50		5	24		4	13
15		56	0	XII	0	3		5	30		4	1
16	XI	56	1	XII	0	16	XII	5	36	XII	3	49
17		56	2		0	29		5	41		3	37
18		56	4		0	42		5	46		3	24
19		56	7		0	55		5	50		3	10
20		56	10		1	8		5	54		2	56
21	XI	56	13	XII	1	21	XII	5	57	XII	2	42
22		56	17		1	34		6	0		2	27
23		56	22		1	47		6	2		2	12
24		56	28		2	0		6	3		1	56
25		56	33		2	13		6	4		1	40
26	XI	56	40	XII	2	25	XII	6	4	XII	1	23
27		56	47		2	38		6	4		1	6
28		56	54		2	50		6	3		0	49
29		57	02		3	02		6	1		0	31
30		57	10		3	14		5	59		0	13
31		57	18					5	56	XI	59	55

A TABLE shewing what Time it ought to be by the Clock when the Sun's Centre is on the Meridian.

The first Year after Leap-Year.

Days	September.			October.			November.			December.		
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.
1	XI	59	36	XI	49	28	XI	43	46	XI	49	38
2		59	[illegible]		49	9		[illegible]	46		50	01
3		58	58		[illegible]	51		43	[illegible]		50	25
4		58	38		[illegible]	33		43	48		50	50
5		58	18		48	15		43	50		51	15
6	XI	57	58	XI	47	58	XI	43	[illegible]	XI	51	41
7		57	[illegible]		47	41		43	57		[illegible]	7
8		57	18		47	24		44	1		[illegible]	34
9		56	[illegible]		[illegible]	8		[illegible]	7		[illegible]	01
10		56	37		46	53		44	13		53	28
11	XI	56	16	XI	46	38	XI	44	21	XI	53	56
12		55	55		46	24		[illegible]	29		54	25
13		55	34		46	10		[illegible]	38		54	54
14		55	13		[illegible]	56		[illegible]	48		55	23
15		54	52		45	[illegible]		44	59		[illegible]	52
16	XI	54	31	XI	[illegible]	32	XI	45	13	XI	56	22
17		54	11		45	20		45	20		56	51
18		53	[illegible]		45	9		45	36		57	21
19		53	29		[illegible]	59		[illegible]	50		57	51
20		53	8		44	49		[illegible]	5		58	21
21	XI	52	47	XI	44	40	XI	46	21	XI	58	51
22		52	27		[illegible]	31		46	37		[illegible]	22
23		52	6		44	[illegible]		46	54		59	52
24		51	46		44	17		47	12	XII	0	22
25		51	25		44	10		47	31		0	52
26	XI	51	5	XI	[illegible]	5	XI	47	51	XII	1	21
27		50	45		[illegible]	0		48	11		1	51
28		50	26		43	[illegible]		48	31		2	20
29		50	6		43	52		[illegible]	53		2	50
30		49	47		[illegible]	49		49	15		3	19
31					43	47					3	47

A TABLE shewing what Time it ought to be by the Clock when the Sun's Centre is on the Meridian.

The second Year after Leap-Year.

Days	January.			February.			March			April.		
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.
1	XII	4	15	XII	14	6	[redacted]	12	35	XII	3	50
2		4	43		14	13		12	23		3	32
3		5	11		14	19		12	9		3	14
4		5	38		14	24		11	[redacted]		2	56
5		6	5		14	29		11	42		2	38
6	[redacted]	6	31	XII	14	32	XII	11	27	XII	2	20
7		6	57		14	35		11	13		2	3
8		7	22		14	37		10	58		1	46
9		7	47		14	39		10	42		1	29
10		8	12		14	39		10	26		1	12
11	XII	8	35	XII	14	39	XII	10	10	XII	0	56
12		8	58		14	38		9	54		0	40
13		9	21		14	36		9	37		0	24
14		9	43		14	34		9	20		0	9
15		10	4		14	31		9	3	XI	59	54
16	XII	10	24	XII	14	27	XII	[redacted]	45	XI	59	39
17		10	44		14	22		8	28		59	25
18		11	3		14	17		8	10		59	11
19		11	22		14	11		7	52		58	58
20		11	39		14	[redacted]		7	34		58	45
21	XII	11	56	XII	13	57	XII	[redacted]	15	XI	58	32
22		12	12		13	49		6	57		58	20
23		12	[redacted]		13	40		6	38		58	8
24		12	41		13	31		6	20		57	56
25		12	55		13	21		6	1		57	45
26	XII	13	7	XII	13	10	XII	5	[redacted]	[redacted]	57	35
27		13	19		12	59		5	24		57	25
28		13	30		12	47		5	5		57	15
29		13	40					4	[redacted]		57	6
30		13	50					4	[redacted]		56	58
31		13	58					4	9			

A TABLE shewing what Time it ought to be by the Clock when the Sun's Centre is on the Meridian.

The second Year after Leap-Year.

Days	May.			June.			July.			August.		
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.
1	XI	56	50	XI	57	24	XII	3	22	XII	5	53
2		56	43		57	33		3	33		5	49
3		56	36		57	42		3	44		5	44
4		56	30		57	52		3	55		5	39
5		56	24		58	3		4	5		5	33
6	XI	56	19	XI	58	13	XII	4	16	XII	5	27
7		56	15		58	24		4	26		5	20
8		56	11		58	35		4	35		5	13
9		56	7		58	47		4	44		5	5
10		56	5		58	59		4	53		4	56
11	XI	56	3	XI	59	11	XII	5	01	XII	4	47
12		56	1		59	23		5	9		4	38
13		56	0		59	37		5	17		4	27
14		56	0		59	48		5	23		4	17
15		56	0	XII	0	01		5	30		4	5
16	XI	56	1	XII	0	14	XII	5	36	XII	3	53
17		56	2		0	27		5	41		3	41
18		56	4		0	40		5	46		3	28
19		56	7		0	53		5	50		3	15
20		56	10		1	6		5	54		3	1
21	XI	56	13	XII	1	19	XII	5	57	XII	2	46
22		56	17		1	31		6	0		2	31
23		56	22		1	44		6	1		2	16
24		56	27		1	57		6	3		2	0
25		56	32		2	10		6	4		1	44
26	XI	56	38	XII	2	22	XII	6	4	XII	1	27
27		56	45		2	34		6	3		1	10
28		56	42		2	46		6	2		0	53
29		56	59		2	58		6	1		0	35
30		57	7		3	10		5	59		0	17
31		57	15					5	56	XI	59	59

A TABLE shewing what Time it ought to be by the Clock when the Sun's Centre is on the Meridian.

The second Year after Leap-Year

Days	September.			October.			November			[illegible]cember.		
	H.	M	S	H	M.	S.	H.	M	S.	H	M	S.
1	XI	59	40	XI	49	32	XI	43	46	[illegible]	49	32
2		59	[illegible]		49	14		43	46		49	56
3		59	2		48	55		43	[illegible]		[illegible]	20
4		58	[illegible]		48	37		43	[illegible]		50	44
5		58	23		48	20		43	50		51	9
6	XI	58	4	XI	48	3	XI	43	53	XI	51	35
7		57	44		47	[illegible]		43	57		52	1
8		57	23		47	29		44	1		52	28
9		57	3		47	14		44	7		52	55
10		56	42		[illegible]	58		44	13		53	23
11	XI	66	22	XI	46	43	XI	44	20	XI	53	51
12		56	1		46	29		44	28		54	19
[illegible]		55	[illegible]		46	15		44	37		[illegible]	48
14		55	20		46	1		44	47		[illegible]	17
15		54	59		45	48		44	57		[illegible]	46
16	XI	54	38	XI	45	36	XI	45	8	XI	56	15
17		54	17		45	[illegible]		45	20		56	45
[illegible]		53	56		45	13		45	[illegible]		57	14
19		53	35		45	2		[illegible]	47		57	44
[illegible]		53	14		44	52		[illegible]	2		58	14
21	XI	52	[illegible]	XI	44	[illegible]	XI	46	17	XI	58	44
22		52	32		[illegible]	34		46	33		59	14
23		52	11		44	26		46	50		59	44
24		51	51		44	18		47	7	XII	0	14
25		51	30		44	11		47	26		0	44
26	XI	51	10	XI	[illegible]	6	XI	47	45	XII	1	13
27		50	50		[illegible]	0		48	5		1	43
28		50	30		43	[illegible]		48	26		2	12
29		50	11		[illegible]	52		48	47		2	42
30		49	51		43	50		49	9		3	11
31					43	48					3	40

A TABLE shewing what Time it ought to be by the Clock when the Sun's Centre is on the Meridian.

The third Year after Leap-Year.

Days	January.			February.			March.			April		
	H.	M	S	H.	M.	S.	H.	M	S	H	M.	S.
1	XII	4	8	XII	14	4	XII	12	38	XII	3	55
2		4	36		14	11		12	25		3	36
3		5	4		14	17		12	12		3	18
4		5	32		14	23		11	59		3	0
5		5	59		14	28		11	45		2	43
6	XII	6	25	XII	14	32	XII	11	31	XII	2	25
7		6	51		14	35		11	17		2	8
8		7	17		14	37		10	2		1	51
9		7	42		14	39		10	46		1	34
10		8	6		14	40		10	31		1	17
11	XII	8	30	XII	14	40	XII	10	14	XII	1	1
12		8	53		14	39		9	58		0	44
13		9	16		14	37		9	41		0	29
14		9	38		14	35		9	24		0	13
15		9	59		14	31		9	7	XI	59	58
16	XII	10	20	XII	14	27	XII	8	49	XI	59	43
17		10	39		14	23		8	32		59	28
18		10	58		14	17		8	14		59	14
19		11	17		14	11		7	55		59	0
20		11	34		14	5		7	37		58	47
21	XII	11	51	XII	13	57	XII	7	19	XI	58	34
22		12	7		13	49		7	0		58	22
23		12	22		13	41		6	42		58	10
24		12	36		13	32		6	23		57	58
25		12	50		13	22		6	4		57	47
26	XII	13	3	XII	13	12	XII	5	46	XI	57	37
27		13	15		13	1		5	27		57	27
28		13	27		12	50		5	8		57	17
29		13	37					4	50		57	8
30		13	47					4	31		57	0
31		13	56					4	13			

A TABLE shewing what Time it ought to be by the Clock when the Sun's Centre is on the Meridian.

The third Year after Leap-Year.

Days.	May. H	M.	S	June. H	M.	S.	July. H.	[illegible]	S.	August. H	M	S
1	XI	56	52	XI	57	22	XII	[illegible]	20	XII	5	54
2		56	45		57	31		3	31		5	50
3		56	38		57	41		3	42		5	46
4		56	32		57	51		3	53		5	41
5		56	26		58	1		4	4		5	35
6	XI	56	21	XI	58	12	XII	4	14	XII	5	29
7		56	17		58	23		4	24		5	22
8		56	13		58	34		4	34		5	[illegible]
9		56	9		58	45		4	43		5	[illegible]
10		56	6		58	57		4	52		4	58
11	XI	56	[illegible]	XI	59	8	XII	5	0	XII	4	49
12		56	2		59	21		5	8		4	40
13		[illegible]	1		59	33		5	15		4	29
14		56	[illegible]		59	45		5	22		4	19
15		56	0		59	58		5	28		4	7
16	XI	56	1	XII	0	10	XII	5	34	XII	3	[illegible]
17		56	2		0	23		[illegible]	39		3	43
18		56	4		0	[illegible]		5	44		3	30
19		56	6		0	49		5	48		3	17
20		56	8		1	1		5	[illegible]		3	3
21	XI	56	11	XII	1	14	XII	5	55	XII	2	48
22		56	15		1	27		5	58		2	34
23		56	20		1	[illegible]		6	0		2	19
24		56	[illegible]		1	53		6	[illegible]		2	3
25		56	30		2	[illegible]		6	3		1	47
26	XI	56	36	XII	2	18	XII	6	3	XII	1	31
27		56	43		2	31		6	3		1	14
28		56	50		2	44		6	2		0	57
29		56	57		2	56		6	1		0	39
30		57	[illegible]		3	[illegible]		5	59		0	22
31		57	13					5	57		0	4

A TABLE shewing what Time it ought to be by the Clock when the Sun's Centre is on the Meridian.

The third Year after Leap-Year.

Days	September.			October.			November.			December.		
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.
1	XI	59	45	XI	49	37	XI	43	47	XI	49	27
2		59	26		49	19		43	47		49	50
3		59	7		49	0		43	47		50	14
4		58	48		48	42		43	47		50	38
5		58	28		48	24		43	49		51	3
6	XI	58	9	XI	48	7	XI	43	52	XI	51	29
7		57	49		47	50		43	55		51	55
8		57	28		47	33		43	59		52	21
9		57	8		47	17		44	4		52	48
10		56	47		47	1		44	10		53	15
11	XI	56	27	XI	46	46	XI	44	17	XI	53	43
12		56	6		46	31		44	25		54	11
13		55	45		46	17		44	33		54	40
14		55	24		46	3		44	43		55	8
15		55	3		45	50		44	53		55	37
16	XI	54	42	XI	45	37	XI	45	4	XI	56	7
17		54	20		45	25		45	16		56	36
18		53	59		45	14		45	29		57	6
19		53	38		45	3		45	42		57	36
20		53	17		44	53		45	57		58	6
21	XI	52	56	XI	44	43	XI	46	12	XI	58	36
22		52	36		44	35		46	28		59	6
23		52	15		44	27		46	45		59	36
24		51	55		44	19		47	3	XII	0	6
25		51	35		44	13		47	21		0	36
26	XI	51	14	XI	44	7	XI	47	40	XII	1	6
27		50	54		44	1		48	0		1	36
28		50	35		43	57		48	21		2	6
29		50	15		43	53		48	42		2	35
30		49	56		43	50		49	4		3	5
31					43	48					3	34

*** OBSERVE by a good meridian-line, or by a transit-instrument, properly fixed, the moment when the Sun's centre is on the meridian; and set the clock to the time marked in the preceding table for that day of the year. Then if the clock goes true, it will point to the time shewn in the table every day afterward at the instant when it is noon by the Sun, which is when his centre is on the meridian.—Thus, in the first year after leap-year, on the 20th of October, when it is noon by the Sun, the true equal time by the clock is only 44 minutes 49 seconds past XI; and on the last day of December (in that year) it should be 3 minutes 47 seconds past XII by the clock when the Sun's centre is on the meridian.

The following table was made from the preceding one, and is of the common form of a table of the equation of time, shewing how much a clock regulated to keep mean or equal time is before or behind the apparent or solar time every day of the year.

A

TABLE

OF THE

EQUATION OF TIME,

SHEWING

How much a Clock should be *faster* or *slower* than the Sun, at the Noon of every Day in the Year, both in Leap-Years and Common Years.

[*The Asterisks in the Table shew where the Equation changes to Slow or Fast.*]

A TABLE of the Equation of Time, shewing how much a Clock should be faster or slower than the Sun, every Day of the Year, at Noon.

The Bissextile, or Leap-Year.

Days.	Jan.		Feb.		March.		April.		May.		June.	
	M.	S.	M.	S.	M.	S.	M.	S.	M	S.	M.	S.
	Clock faster.		Clock faster.		Clock faster.		Clock faster.		Clock slower.		Clock slower.	
1	4	2	14	3	12	30	3	42	3	12	2	30
2	4	30	14	10	12	17	3	24	3	19	2	20
3	4	58	14	16	12	4	3	6	3	26	2	11
4	5	25	14	22	11	50	2	48	3	32	2	1
5	5	52	14	27	11	35	2	30	3	37	1	51
6	6	19	14	31	11	21	2	13	3	42	1	40
7	6	45	14	34	11	6	1	55	3	46	1	29
8	7	10	14	37	10	50	1	38	3	50	1	18
9	7	35	14	38	10	34	1	21	3	53	1	6
10	8	00	14	39	10	18	1	4	3	55	0	54
11	8	24	14	39	10	2	0	48	3	57	0	42
12	8	47	14	38	9	45	0	32	3	59	0	30
13	9	10	14	37	9	28	0	17	4	00	0	18
14	9	32	14	35	9	11	0	1	4	00	0	5
15	9	53	14	32	8	54	0 *	13	3	59	0 *	8
							Clock slower.				Clock faster.	
16	10	14	14	28	8	36	0	28	3	58	0	21
17	10	34	14	24	8	18	0	42	3	56	0	33
18	10	53	14	19	8	00	0	56	3	54	0	46
19	11	12	14	13	7	42	1	9	3	51	0	59
20	11	30	14	7	7	24	1	22	3	48	1	13
21	11	47	14	00	7	6	1	34	3	44	1	26
22	12	3	13	52	6	47	1	46	3	40	1	39
23	12	19	13	44	6	29	1	57	3	35	1	52
24	12	34	13	35	6	10	2	8	3	30	2	5
25	12	48	13	26	5	52	2	19	3	24	2	17
26	13	1	13	16	5	33	2	29	3	17	2	30
27	13	13	13	5	5	15	2	39	3	10	2	42
28	13	25	12	54	4	56	2	48	3	3	2	54
29	13	36	12	42	4	37	2	56	2	55	3	6
30	13	46			4	19	3	4	2	47	3	18
31	13	55			4	00			2	39		

A TABLE of the Equation of Time, shewing how much a Clock should be faster or slower than the Sun, every Day of the Year, at Noon.

The Bissextile, or Leap-Year.

Days.	July. M. S.	Aug. M. S.	Sept. M. S.	Oct. M S.	Nov. M. S.	Dec. M. S.
	Clock faster.	Clock faster.	Clock slower.	Clock slower.	Clock slower.	Clock slower.
1	3 29	5 51	0 30	10 38	16 15	10 17
2	3 40	5 47	0 49	10 57	16 15	9 53
3	3 51	5 42	1 8	11 15	16 15	9 29
4	4 1	5 36	1 28	11 33	16 13	9 4
5	4 12	5 30	1 48	11 51	16 11	8 39
6	4 22	5 23	2 8	12 8	16 7	8 13
7	4 31	5 16	2 28	12 24	16 3	7 47
8	4 40	5 8	2 48	12 41	15 58	7 20
9	4 49	5 00	3 9	12 56	15 52	6 52
10	4 57	4 51	3 30	13 12	15 46	6 25
11	5 5	4 41	3 50	13 27	15 38	5 57
12	5 13	4 31	4 11	13 41	15 29	5 28
13	5 20	4 21	4 32	13 55	15 20	4 59
14	5 26	4 10	4 53	14 8	15 10	4 30
15	5 32	3 58	5 14	14 20	14 59	4 00
16	5 38	3 46	5 35	14 32	14 47	3 31
17	5 43	3 33	5 56	14 44	14 34	3 1
18	5 48	3 20	6 16	14 54	14 21	2 31
19	5 52	3 6	6 37	15 5	14 7	2 1
20	5 56	2 52	6 58	15 14	13 52	1 31
21	5 59	2 38	7 19	15 23	13 36	1 1
22	6 1	2 23	7 40	15 31	13 19	0 31
23	6 3	2 7	8 00	15 39	13 2	0 1
24	6 4	1 51	8 20	15 46	12 44	0 * 29
25	6 4	1 35	8 41	15 52	12 25	0 59
26	6 4	1 18	9 1	15 58	12 5	1 29
27	6 4	1 1	9 21	16 3	11 45	1 58
28	6 2	0 44	9 41	16 7	11 24	2 27 faster.
29	6 00	0 26	10 00	16 10	11 2	2 56
30	5 58	0 8	10 19	16 12	10 40	3 25
31	5 55	0 * 11		16 14		3 54

A TABLE of the Equation of Time, shewing how much a Clock should be faster or slower than the Sun, every Day of the Year, at Noon.

The first Year after Leap-Year.

Days.	Jan.		Feb.		March.		April.		May.		June.	
	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.
1	4	23	14	9	12	33	3	47	3	11	2	33
2	4	51	14	16	12	20	3	29	3	18	2	24
3	5	19	14	21	12	7	3	10	3	25	2	14
4	5	46	14	26	11	54	2	52	3	31	2	4
5	6	13	14	31	11	40	2	35	3	36	1	54
6	6	39	14	34	11	25	2	17	3	41	1	43
7	7	4	14	37	11	10	2	00	3	45	1	33
8	7	30	14	39	10	55	1	43	3	49	1	22
9	7	54	14	40	10	39	1	26	3	53	1	10
10	8	18	14	40	10	23	1	9	3	55	0	58
11	8	41	14	39	10	7	0	52	3	57	0	46
12	9	4	14	38	9	50	0	36	3	59	0	34
[illegible]	9	26	14	36	9	33	0	20	4	00	0	22
14	9	48	14	33	9	16	0	5	4	00	0	10
15	10	9	14	29	8	58	0 •	10	4	00	0 •	3
16	10	29	14	25	8	41	0	25	3	59	0	16
17	10	48	14	20	8	23	0	39	3	58	0	29
[illegible]	11	7	14	15	8	5	0	53	3	56	0	42
19	11	25	14	9	7	47	1	6	3	53	0	55
20	11	42	14	2	7	29	1	19	3	50	1	8
21	11	59	13	54	7	10	1	32	3	47	1	21
22	12	15	13	46	6	52	1	44	3	42	1	34
23	12	30	13	37	6	33	1	56	3	38	1	47
24	12	44	13	28	6	15	2	7	3	32	2	00
25	12	58	13	18	5	56	2	17	3	26	2	13
26	13	10	13	8	5	38	2	28	3	20	2	25
27	13	22	12	57	5	19	2	37	3	13	2	38
28	13	33	12	45	5	00	2	46	3	6	2	50
29	13	43			4	42	2	55	2	58	3	2
30	13	52			4	23	3	3	2	50	3	14
31	14	1			4	5			2	42		

A TABLE of the Equation of Time, shewing how much a Clock should be faster or slower than the Sun, every Day of the Year, at Noon.

The first Year after Leap-Year.

Days	July. Clock faster.		Aug. Clock faster.		Sept. Clock slower.		Oct. Clock slower.		Nov. Clock slower.		Dec. Clock slower. … faster.	
	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.
1	3	26	5	52	0	24	10	32	16	14	10	22
2	3	37	5	48	0	43	10	51	16	14	9	59
3	3	48	5	43	1	2	11	9	16	13	9	35
4	3	58	5	38	1	22	11	27	16	12	9	10
5	4	9	5	32	1	42	11	45	16	10	8	45
6	4	19	5	25	2	2	12	2	16	7	8	19
7	4	28	5	18	2	22	12	19	16	3	7	53
8	4	37	5	10	2	42	12	35	15	59	7	26
9	4	46	5	2	3	3	12	51	15	53	6	59
10	4	55	4	53	3	23	13	7	15	47	6	31
11	5	3	4	44	3	44	13	22	15	39	6	3
12	5	10	4	34	4	5	13	36	15	31	5	35
13	5	17	4	24	4	26	13	50	15	22	5	6
14	5	24	4	13	4	47	14	3	15	12	4	37
15	5	30	4	1	5	8	14	16	15	1	4	8
16	5	36	3	49	5	29	14	28	14	50	3	38
17	5	41	3	37	5	50	14	40	14	37	3	9
18	5	46	3	24	6	10	14	51	14	24	2	39
19	5	50	3	10	6	31	15	1	14	10	2	9
20	5	54	2	54	6	52	15	11	13	55	1	39
21	5	57	2	42	7	13	15	20	13	39	1	9
22	6	00	2	27	7	33	15	29	13	23	0	38
23	6	2	2	12	7	54	15	36	13	6	0	8
24	6	3	1	56	8	14	15	43	12	48	0 *	22
25	6	4	1	40	8	35	15	50	12	29	0	52
26	6	4	1	23	8	55	15	55	12	9	1	22
27	6	4	1	6	9	15	16	00	11	49	1	51
28	6	3	0	49	9	34	16	4	11	28	2	20
29	6	1	0	31	9	54	16	8	11	7	2	50
30	5	59	0	13	10	13	16	11	10	45	3	19
31	5	56	0 *	5			16	13			3	47

A TABLE of the Equation of Time, shewing how much a Clock should be faster or slower than the Sun, every Day of the Year, at Noon.

The second Year after Leap-Year.

Days.	Jan		Feb.		March.		April.		May.		June.	
	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.
	Clock faster.		Clock faster.		Clock faster.		Clock faster.		Clock slower.		Clock slower.	
1	4	15	14	6	12	35	3	50	3	10	2	36
2	4	43	14	13	12	23	3	32	3	17	2	27
3	5	11	14	19	12	9	3	14	3	24	2	17
4	5	38	14	24	11	56	2	56	3	30	2	8
5	6	5	14	28	11	42	2	38	3	36	1	57
6	6	31	14	32	11	27	2	20	3	41	1	47
7	6	57	14	35	11	13	2	3	3	45	1	36
8	7	22	14	37	10	58	1	46	3	49	1	25
9	7	47	14	39	10	42	1	29	3	52	1	13
10	8	11	14	39	10	26	1	12	3	55	1	1
11	8	35	14	39	10	10	0	56	3	57	0	49
12	8	58	14	38	9	54	0	40	3	59	0	37
13	9	21	14	36	9	37	0	24	4	00	0	24
14	9	43	14	34	9	20	0	9	4	00	0	12
15	10	4	14	31	9	3	0 *	6	4	00	0 *	1
							Clock slower.				Clock faster.	
16	10	24	14	27	8	45	0	21	3	59	0	14
17	10	44	14	22	8	27	0	35	3	58	0	27
18	11	3	14	17	8	10	0	49	3	56	0	40
19	11	22	14	11	7	52	1	2	3	53	0	53
20	11	39	14	4	7	34	1	15	3	50	1	6
21	11	56	13	57	7	15	1	28	3	47	1	19
22	12	12	13	49	6	57	1	40	3	43	1	32
23	12	27	13	40	6	38	1	52	3	38	1	44
24	12	41	13	31	6	20	2	4	3	33	1	57
25	12	55	13	21	6	1	2	15	3	28	2	10
26	13	7	13	10	5	42	2	25	3	22	2	22
27	13	19	12	59	5	23	2	35	3.	15	2	34
28	13	30	12	47	5	5	2	45	3	8	2	46
29	13	40			4	46	2	54	3	1	2	58
30	13	50			4	27	3	2	3	53	3	10
31	13	58			4	9			2	45		

A TABLE of the Equation of Time, shewing how much a Clock should be faster or slower than the Sun, every Day of the Year, at Noon.

The second Year after Leap-Year.

Days.	July.		Aug.		Sept.		Oct.		Nov.		Dec.	
	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.
	Clock faster.		Clock faster.		Clock slower.		Clock slower.		Clock slower.		Clock slower. (27–29: faster.)	
1	3	22	5	53	0	20	10	28	16	14	10	28
2	3	33	5	49	0	39	10	46	16	14	10	4
3	3	44	5	44	0	58	11	5	16	14	9	40
4	3	55	5	39	1	17	11	23	16	12	9	16
5	4	5	5	33	1	37	11	40	16	10	8	51
6	4	16	5	27	1	56	11	57	16	7	8	25
7	4	26	5	20	2	16	12	14	16	3	7	59
8	4	35	5	13	2	37	12	30	15	59	7	32
9	4	44	5	5	2	57	12	46	15	53	7	5
10	4	53	4	56	3	17	13	2	15	47	6	37
11	5	1	4	47	3	38	13	17	15	40	6	9
12	5	9	4	37	3	59	13	31	15	32	5	41
13	5	17	4	27	4	19	13	45	15	23	5	12
14	5	24	4	17	4	40	13	59	15	13	4	43
15	5	30	4	5	5	1	14	12	15	3	4	14
16	5	36	3	53	5	22	14	24	14	52	3	45
17	5	41	3	41	5	43	14	36	14	40	3	15
18	5	46	3	28	6	4	14	47	14	27	2	46
19	5	50	3	15	6	25	14	58	14	13	2	16
20	5	54	3	1	6	46	15	8	13	58	1	46
21	5	57	2	46	7	7	15	18	13	43	1	16
22	6	00	2	31	7	28	15	26	13	27	0	46
23	6	2	2	16	7	49	15	34	13	10	0	16
24	6	3	2	00	8	9	15	42	12	52	0	14
25	6	4	1	44	8	30	15	49	12	34	0	44
26	6	4	1	27	8	50	15	54	12	15	1	13
27	6	3	1	10	9	10	15	59	11	55	1	43
28	6	2	0	53	9	30	16	4	11	34	2	12
29	6	1	0	35	9	49	16	8	11	13	2	42
30	5	59	0	17	10	9	16	11	10	51	3	11
31	5	56	0 *	1			16	12			3	40

A TABLE of the Equation of Time, shewing how much a Clock should be faster or slower than the Sun, every Day of the Year, at Noon.

The Third Year after Leap-Year.

Days.	Jan. M.	S.	Feb. M.	S.	March. M.	S.	April. M.	S.	May. M.	S.	June. M.	S.
1	4	8	14	4	12	38	3	55	3	8	2	38
2	4	36	14	11	12	25	3	36	3	15	2	29
3	5 Clock	4	14 Clock	17	11 Clock	12	3 Clock	18	3 Clock	22	2 Clock	19
4	5	32	14	23	11	59	3	00	3	28	2	9
5	5	59	14	28	11	45	2	43	3	34	1	59
6	6	25	14	32	11	31	2	25	3	39	1	48
7	6	51	14	35	11	17	2	8	3	43	1	37
8	7 faster.	17	14 faster.	37	11 faster.	2	1 faster.	51	3 slower.	47	1 slower.	26
9	7	42	14	39	10	46	1	34	3	51	1	15
10	8	6	14	40	10	30	1	17	3	54	1	3
11	8	30	14	40	10	14	1	1	3	56	0	51
12	8	53	14	39	9	58	0	45	3	58	0	39
13	9	16	14	37	9	41	0	29	3	59	0	27
14	9	38	14	35	9	24	0	13	4	00	0	15
15	9	59	14	31	9	7	0 *	2	4	00	0	2
16	10	20	14	27	8	49	0	17	3	59	0 *	10
17	10	39	14	23	8	32	0	32	3	58	0	23
18	10	58	14	17	8	14	0 Clock	46	3	56	0 Clock	36
19	11	16	14	11	7	56	1	00	3	54	0	49
20	11	34	14	5	7	37	1	13	3	52	1	2
21	11	51	13	57	7	19	1	26	3	49	1	14
22	12	7	13	49	7	00	1	38	3	45	1	27
23	12	22	13	41	6	42	1 slower.	50	3	40	1 faster.	40
44	12	36	13	32	6	23	2	2	3	35	1	53
25	12	50	13	22	6	4	2	13	3	30	2	6
26	13	3	13	12	5	46	2	23	3	24	2	18
27	13	15	13	1	5	27	2	33	3	17	2	31
28	13	26	12	50	5	8	2	43	3	10	2	43
29	13	37			4	50	2	52	3	3	2	56
30	13	47			4	31	3	00	2	55	3	8
31	13	56			4	13			2	47		

A TABLE of the Equation of Time, shewing how much a Clock should be faster or slower than the Sun, every Day of the Year, at Noon.

The third Year after Leap-Year.

Days.	July.		Aug.		Sept.		Oct.		Nov.		Dec.	
	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.
	Clock faster.		Clock faster.		Clock slower.		Clock slower.		Clock slower.		Clock slower.	
1	3	20	5	54	0 *	15	10	23	16	13	10	33
2	3	31	5	50	0	34	10	42	16	14	10	10
3	3	42	5	46	0	53	11	00	16	14	9	46
4	3	53	5	41	1	12	11	18	16	13	9	22
5	4	4	5	35	1	32	11	36	16	11	8	57
6	4	14	5	29	1	51	11	53	16	8	8	31
7	4	24	5	22	2	11	12	10	16	5	8	5
8	4	34	5	15	2	32	12	27	16	1	7	39
9	4	43	5	7	2	52	12	43	15	55	7	12
10	4	52	4	58	3	13	12	59	15	49	6	45
11	5	00	4	49	3	34	13	14	15	43	6	17
12	5	8	4	40	3	54	13	29	15	35	5	49
13	5	15	4	29	4	15	13	43	15	27	5	20
14	5	22	4	18	4	36	13	57	15	17	4	52
15	5	28	4	7	4	57	14	10	15	7	4	23
16	5	34	3	55	5	18	14	23	14	56	3	54
17	5	39	3	43	5	40	14	35	14	44	3	24
18	5	44	3	30	6	1	14	46	14	31	2	54
19	5	48	3	17	6	22	14	57	14	18	2	24
20	5	52	3	3	6	43	15	7	14	3	1	54
21	5	55	2	48	7	4	15	17	13	48	1	24
22	5	58	2	34	7	24	15	25	13	32	0	54
23	6	00	2	19	7	45	15	33	13	15	0	24
24	6	2	2	3	8	5	15	41	12	57	0 *	6
25	6	3	1	47	8	25	15	48	12	39	0	36
											faster.	
26	6	3	1	31	8	46	15	53	12	20	1	6
27	6	3	1	14	9	6	15	59	12	00	1	36
28	6	2	0	57	9	25	16	3	11	39	2	6
29	6	1	0	39	9	45	16	7	11	18	2	35
30	5	59	0	22	10	4	16	10	10	56	3	5
31	5	57	0	4			16	12			3	34

A concise EQUATION-TABLE, adapted to the Second Year after Leap-Year, and which will be within a Minute of the Truth for every Year; shewing, to the nearest full Minute, how much a Clock should be faster or slower than the Sun. *By Mr.* SMEATON.

Months.	Days.	Equ. in Minutes.		Months.	Days.	Equ. in Minutes.		Months.	Days.	Equ. in Minutes.		Months.	Days.	Equ. in Minutes.	
Jan.	1	4	Clock faster than the Sun.	Apr.	1	4	Clock faster,	Aug.	10	5	Clock faster.	Oct.	27	16	Clock slower than the Sun.
	3	5			4	3			15	4		Nov.	8	16	
	5	6			7	2			20	3			15	15	
	7	7			11	1			24	2			20	14	
	10	8			15	0			28	1			24	13	
	12	9			*				31	0			27	12	
	15	10			19	1	Clock slower.		*				30	11	
	18	11			24	2		Sept.	3	1	Clock slower than the Sun.	Dec.	2	10	
	21	12		May	30	3			6	2			5	9	
	25	13			14	4			9	3			7	8	
	31	14		June	29	3			[illegible]	4			9	7	
Feb.	6	15			5	2			15	5			11	6	
	21	14			10	1			18	6			13	5	
	27	13			15	0			[illegible]	7			15	4	
Mar.	4	12			*				24	8			18	3	
	8	11			20	1	Clock faster.		27	9			20	2	
	12	10			24	2			30	10			22	1	
	15	9		July	29	3		Oct.	3	11			24	[illegible]	
	19	8			4	4			6	12			*		
	22	7			11	5			10	13			[illegible]	1	Faster.
	25	6			26	6			14	14			28	2	
	28	5							19	15			30	3	

This table is near enough the truth for regulating common clocks and watches. It may be easily copied by the pen, and, being doubled, may be put into a pocket-book.

CHAP. XV.

The Moon's Surface mountainous: Her Phases described: Her Path, and the Paths of Jupiter's Moons delineated: The Proportions of the Diameters of their Orbits, and those of Saturn's Moons, to each other; and the Diameter of the Sun.

252. BY looking at the Moon through an ordinary telescope, we perceive that her surface is diversified with long tracts of prodigious high mountains and deep cavities. Some of her mountains, by comparing their height with her diameter (which is 2180 miles,) are found to be three times as high as the highest mountains on our Earth. This ruggedness of the Moon's surface is of great use to us, by reflecting the Sun's light to all sides: for if the Moon were smooth and polished like a looking-glass, or covered with water, she could never distribute the Sun's light all round: only, in some positions, she would shew us his image, no bigger than a point, but with such a lustre as might be hurtful to our eyes.

PLATE VII.

The Moon's surface mountainous.

253. The Moon's surface being so uneven, many have wondered why her edge appears not jagged as well as the curve bounding the light and dark parts. But if we consider, that what we call the edge of the Moon's disc is not a single line set round with mountains, in which case it would appear irregularly indented, but a large zone, having many mountains lying behind one another from the observer's eye, we shall find that the mountains in some rows will be opposite to the vales in others, and fill up the inequalities, so as to make her appear quite round; just as when one looks at an orange, although its roughness be very discernible on the side next the eye, especially if the Sun or a candle shines obliquely on that side, yet the line terminating the visible part still appears smooth and even.

Why no hills appear on her edge.

PLATE VII.

The Moon has no twilight.

254. As the Sun can only enlighten that half of the Earth which is at any moment turned toward him, and being withdrawn from the opposite half, leaves it in darkness; so he likewise doth to the Moon; only with this difference, that the Earth being surrounded by an atmosphere, and the Moon, as far as we know, having none, we have twilight after the Sun sets; but the Lunar inhabitants have an immediate transition from the brightest sunshine to the blackest darkness, § 177. For, let *t r k s w* be the Earth, and *A*, *B*, *C*, *D*, *E*, *F*, *G*, *H*, the Moon, in eight different parts of her orbit. As the Earth turns round its axis, from west to east, when any place comes to *t*, the twilight begins there, and when it revolves from thence to *r*, the Sun *S* rises; when the place comes to *s*, the Sun sets, and when it comes to *w*, the twilight ends. But as the Moon turns round her axis, which is only once a month, the moment that any point of her surface comes to *r* (see the Moon at *G*) the Sun rises there without any previous warning by twilight; and when the same point comes to *s* the Sun sets, and that point goes into darkness as black as at midnight.

Fig. I.

The Moon's phases.

255. The Moon being an opaque spherical body (for her hills take off no more from her roundness than the inequalities on the surface of an orange take off from its roundness), we can only see that part of the enlightened half of her which is toward the Earth. And therefore when the Moon is at *A*, in conjunction with the Sun *S*, her dark half is toward the Earth, and she disappears, as at *a*; there being no light on that half to render it visible. When she comes to her first octant at *B*, or has gone an eighth part of her orbit from her conjunction, a quarter of her enlightened side is seen toward the Earth, and she appears horned, as at *h*. When she has gone a quarter of her orbit from between the Earth and Sun to *C*, she shows us one half of her enlightened side, as at *c*; and we say, she is a quarter old. At *D* she is in her second octant, and by shewing us more of her

enlightened side she appears gibbous, as at *d*. At *E* her whole enlightened side is toward the Earth, and therefore she appears round as at *e*; when we say it is full Moon. In her third octant at *F*, part of her dark side being toward the Earth, she again appears gibbous, and is on the decrease, as at *f*. At *G* we see just one half of her enlightened side, and she appears half-decreased, or in her third quarter, as at *g*. At *H* we only see a quarter of her enlightened side, being in her fourth octant, where she appears horned, as at *h*. And at *A*, having completed her course from the Sun to the Sun again, she disappears; and we say, it is new Moon. Thus, in going from *A* to *E*, the Moon seems continually to increase; and in going from *E* to *A*, to decrease in the same proportion; having like phases at equal distances from *A* to *E*; but as seen from the Sun *S*, she is always full.

256. The Moon appears not perfectly round when she is full in the highest or lowest part of her orbit, because we have not a full view of her enlightened side at that time. When full in the highest part of her orbit a small deficiency appears on her lower edge; and the contrary, when full in the lowest part of her orbit.

The Moon's disc not always quite round when full.

257. It is plain by the figure, that when the Moon changes to the Earth, the Earth appears full to the Moon; and *vice versâ*. For when the Moon is at *A*, new to the Earth, the whole enlightened side of the Earth is toward the Moon; and when the Moon is at *E*, full to the Earth, its dark side is toward her. Hence a *new Moon* answers to a *full Earth*, and a *full Moon* to a *new Earth*. The *quarters* are also reversed to each other.

The phases of the Earth and Moon contrary.

258. Between the third quarter and change, the Moon is frequently visible in the forenoon, even when the Sun shines; and then she affords us an opportunity of seeing a very agreeable appearance, wherever we find a globular stone above the level of the eye,

An agreeable phenomenon.

as suppose on the top of a gate. For, if the Sun shines on the stone, and we place ourselves so as the upper part of the stone may just seem to touch the point of the Moon's lowermost horn, we shall then see the enlightened part of the stone exactly of the same shape with the Moon; horned as she is, and inclined in the same way to the horizon. The reason is plain; for the Sun enlightens the stone the same way as he does the Moon: and both being globes, when we put ourselves into the above situation, the Moon and stone have the same position to our eye; and therefore we must see as much of the illuminated part of the one as of the other.

The nonagesimal degree what.

259. The position of the Moon's cusps, or a right line touching the points of her horns, is very differently inclined to the horizon at different hours of the same days of her age. Sometimes she stands, as it were, upright on her lower horn, and then such a line is perpendicular to the horizon; when this happens, she is in what the astronomers call *the nonagesimal degree;* which is the highest point of the ecliptic above the horizon at that time, and is 90 degrees from both sides of the horizon, where it is then cut by the ecliptic. But this never happens when the Moon is on the meridian, except when she is at the very beginning of Cancer or Capricorn.

How the inclination of the ecliptic may be found by the position of the Moon's horns.

260. The inclination of that part of the ecliptic to the horizon in which the Moon is at any time when horned, may be known by the position of her horns; for a right line touching their points is perpendicular to the ecliptic. And as the angle which the Moon's orbit makes with the ecliptic can never raise her above, nor depress her below the ecliptic, more than two minutes of a degree, as seen from the Sun; it can have no sensible effect upon the position of her horns. Therefore, if a quadrant be held up, so as that one of its edges may seem to touch the Moon's horns, the graduated side being kept toward the eye, and as far from the eye as it can be conveniently held, the

arc between the plumb-line and that edge of the quadrant which seems to touch the Moon's horns, will shew the inclination of that part of the ecliptic to the horizon. And the arc between the other edge of the quadrant and plumb-line, will shew the inclination of a line, touching the Moon's horns, to the horizon. PLATE VII.

261. The Moon generally appears as large as the Sun; for the angle $v\,k\,A$, under which the Moon is seen from the Earth, is nearly the same with the angle LkM, under which the Sun is seen from it. And therefore the Moon may hide the Sun's whole disc from us, as she sometimes does in solar eclipses. The reason why she does not eclipse the Sun at every change, shall be explained hereafter. If the Moon were farther from the Earth, as at a, she would never hide the whole of the Sun from us; for then she would appear under the angle $N\,k\,O$, eclipsing only that part of the Sun which lies between N and O; were she still farther from the Earth, as at X, she would appear under the small angle $T\,k\,W$, like a spot on the Sun, hiding only the part $T\,W$ from our sight. Fig. I. Why the Moon appears as big as the Sun.

262. That the Moon turns round her axis in the time that she goes round her orbit, is quite demonstrable; for a spectator at rest, without the periphery of the Moon's orbit, would see all her sides turned regularly toward him in that time. She turns round her axis from any star to the same star again in 27 days 8 hours; from the Sun to the Sun again, in 29½ days: the former is the length of her sidereal day, and the latter the length of her solar day. A body moving round the Sun would have a solar day in every revolution, without turning on its axis; the same as if it had kept all the while at rest, and the Sun moved round it: but without turning round its axis it could never have one sidereal day, because it would always keep the same side toward any given star. A proof of the Moon's turning round her axis.

Her periodical and synodical revolution.

263. If the Earth had no annual motion, the Moon would go round it so as to complete a lunation, a sidereal, and a solar day, all in the same time. But because the Earth goes forward in its orbit while the Moon goes round the Earth in her orbit, the Moon must go as much more than round her orbit from change to change in completing a solar day, as the Earth has gone forward in its orbit during that time, *i. e.* almost a twelfth part of a circle.

Familiarly represented.

264. The Moon's periodical and synodical revolution may be familiarly represented by the motions of the hour and minute-hands of a watch round its dial-plate, which is divided into 12 equal parts or hours, as the ecliptic is divided into 12 signs, and the year into 12 months. Let us suppose these 12 hours to be 12 signs, the hour-hand, the Sun, and the minute-hand, the Moon; then the former will go round once in a year, and the latter once in a month: but the Moon, or minute-hand, must go more than round from any point of the circle where it was last conjoined with the Sun, or hour-hand, to overtake it again: for the hour-hand, being in motion, can never be overtaken by the minute-hand at that point from which they started at their last conjunction. The first

A Table shewing the times that the hour and minute-hands of a watch are in conjunction.

Conj.	H.	M.	S.	‴	⁗	vp".
1	I	5	27	16	21	$49\frac{1}{11}$
2	II	10	54	32	43	$38\frac{2}{11}$
3	III	16	21	49	5	$27\frac{3}{11}$
4	IV	21	49	5	27	$16\frac{4}{11}$
5	V	27	10	21	49	$5\frac{5}{11}$
6	VI	32	43	38	10	$54\frac{6}{11}$
7	VII	[illegible]	10	54	32	$43\frac{7}{11}$
8	VIII	43	38	10	54	$32\frac{8}{11}$
9	IX	49	5	27	16	$21\frac{9}{11}$
10	X	54	32	43	38	$10\frac{10}{11}$
11	XII	0	0	0	0	0^{11}

column of the preceding table shews the number of conjunctions which the hour and minute-hand make while the hour-hand goes once round the dial-plate; and the other columns shew the times when the two hands meet at each conjunction. Thus, suppose the two hands to be in conjunction at XII. as they always are; then at the first following conjunction it is 5 minutes 27 seconds 16 thirds 21 fourths, $49\frac{1}{11}$ fifths past I, where they meet: at the second conjunction it is 10 minutes 54 seconds 32 thirds 43 fourths $38\frac{2}{11}$ fifths past II; and so on. This, though an easy illustration of the motions of the Sun and Moon, is not precise as to the times of their conjunctions; because, while the Sun goes round the ecliptic, the Moon makes $12\frac{1}{3}$ conjunctions with him; but the minute-hand of a watch or clock makes only 11 conjunctions with the hour-hand in one period round the dial-plate. But if, instead of the common wheel-work at the back of the dial-plate, the axis of the minute-hand had a pinion of 6 leaves turning a wheel of 74, and this last turning the hour-hand, in every revolution it makes round the dial-plate, the minute-hand would make $12\frac{1}{3}$ conjunctions with it; and so would be a pretty device for shewing the motions of the Sun and Moon; especially, as the slowest moving hand might have a little sun fixed on its point, and the quickest, a little moon.

PLATE VII.

The Moon's motion through open space describ-ed.

265. If the Earth had no annual motion, the Moon's motion, round the Earth, and her track in open space, would be always the same.* But as the Earth and Moon move round the Sun, the Moon's real path in the heavens is very different from her visible path round the Earth: the latter be-

* In this place, we may consider the orbits of all the satellites as circular, with respect to their primary planets; because the eccentricities of their orbits are too small to affect the phenomena here described.

PLATE VII. ing in a progressive circle, and the former in a curve of different degrees of concavity, which would always be the same in the same parts of the heavens, if the Moon performed a complete number of lunations in a year, without any fraction.

An idea of the Earth's path, and the Moon's.

266. Let a nail in the end of the axle of a chariot-wheel represent the Earth, and a pin in the nave the Moon; if the body of the chariot be propped up so as to keep that wheel from touching the ground, and the wheel be then turned round by hand, the pin will describe a circle both round the nail and in the space it moves through. But if the props be taken away, the horses put to, and the chariot driven over a piece of ground which is circularly convex; the nail in the axle will describe a circular curve, and the pin in the nave will still describe a circle round the progressive nail in the axle, but not in the space through which it moves. In this case the curve described by the nail, will resemble, in miniature, as much of the Earth's annual path round the Sun, as it describes while the Moon goes as often round the Earth as the pin does round the nail: and the curve described by the nail will have some resemblance to the Moon's path during so many lunations.

Let us now suppose that the radius of the circular curve described by the nail in the axle is to the radius of the circle which the pin in the nave describes round the axle as $337\frac{1}{2}$ to 1; which is the proportion of the radius or semi-diameter of the Earth's orbit to that of the Moon's; or of the circular curve *A* 1 2 3 4 5 6 7 *B*, &c. to the little circle *a;* and then while the progressive nail describes the said curve from *A* to *E*, the pin will go once round the nail with regard to the centre of its path, and in so doing, will describe the curve *a b c d e*. The former will be a true representation of the Earth's path for one lunation, and the latter of the Moon's for that time. Here we may set aside the inequalities of the Moon's motion, and also those of the

Earth's moving round their common centre of gravity: all which, if they were truly copied in this experiment, would not sensibly alter the figure of the paths described by the nail and pin, even though they should rub against a plane upright surface all the way, and leave their tracks visibly upon it. And if the chariot were driven forward on such a convex piece of ground, so as to turn the wheel several times round, the track of the pin in the nave would still be concave toward the centre of the circular curve described by the pin in the axle: as the Moon's path is always concave to the Sun in the centre of the Earth's annual orbit. PLATE VII.

In this diagram, the thickest curve-line *ABCDE*, with the numeral figures set to it, represents as much of the Earth's annual orbit as it describes in 32 days from west to east; the little circles at *a*, *b*, *c*, *d*, *e*, shew the Moon's orbit in due proportion to the Earth's; and the smallest curve *a b c d e f* represents the line of the Moon's path in the heavens for 32 days, accounted from any particular new Moon at *a*. The machine Fig. 5th, is for delineating the Moon's path, and shall be described, with the rest of my astronomical machinery in the last chapter. The Sun is supposed to be in the centre of the curve *A* 1 2 3 4 5 6 7 *B*, &c. and the small dotted circles upon it, represent the Moon's orbit, of which the radius is in the same proportion to the Earth's path in this scheme, that the radius of the Moon's orbit in the heavens bears to the radius of the Earth's annual path round the Sun: that is, as 240,000, to 81,000,000*, or as 1 to 337½. Proportion of the Moon's orbit to the Earth's.

When the Earth is at *A*, the new Moon is at *a*; and in the seven days that the Earth describes the curve 1 2 3 4 5 6 7, the Moon in accompanying the Earth describes the curve *a b*; and is in her first quarter at *b* when the Earth is at *B*. As the Earth Fig. II.

* For the true distances, see p. 138.

PLATE VII. describes the curve *B* 8 9 10 11 12 13 14, the Moon describes the curve *b c;* and is at *c*, opposite to the Sun, when the Earth is at *C*. While the Earth describes the curve *C* 15 16 17 18 19 20 21 22, the Moon describes the curve *c d;* and is in her third quarter at *d* when the Earth is at *D*. And lastly, while the Earth describes the curve *D* 23 24 25 26 27 28 29, the Moon describes the curve *d e:* and is again in conjunction at *e* with the Sun when the Earth is at *E*, between the 29th and 30th day of the Moon's age, accounted by the numeral figures from the new Moon at *A*. In describing the curve *a b c d e*, the Moon goes round the progressive Earth as really as if she had kept in the dotted circle *A*, and the Earth continued immoveable in the centre of that circle.

The Moon's motion always concave toward the Sun.

And thus we see that, although the Moon goes round the Earth in a circle, with respect to the Earth's centre, her real path in the heavens is not very different in appearance from the Earth's path. To shew that the Moon's path is concave to the Sun, even at the time of change, it is carried on a little farther into a second lunation, as to *f*.

How her motion is alternately retarded and accelerated.

267. The Moon's absolute motion from her change to her first quarter, or from *a* to *b*, is so much slower than the Earth's, that she falls 240 thousand miles (equal to the semi-diameter of her orbit) behind the Earth at her first quarter in *b*, when the Earth is at *B;* that is, she falls back a space equal to her distance from the Earth. From that time her motion is gradually accelerated to her opposition or full at *c*, and then she is come up as far as the Earth, having regained what she lost in her first quarter from *a* to *b*. From the full to the last quarter at *d*, her motion continues accelerated, so as to be just as far before the Earth at *d*, as she was behind it at her first quarter in *b*. But from *d* to *e* her motion is retarded, so that she loses as much with respect to the Earth as is equal to her distance from it, or to the semi-diameter of her orbit; and by that means

she comes to *e*, and is then in conjunction with the Sun as seen from the Earth at *E*. Hence we find, that the Moon's absolute motion is slower than the Earth's from her third quarter to her first; and swifter than the Earth's from her first quarter to her third; her path being less curved than the Earth's in the former case, and more in the latter. Yet it is still bent the same way toward the Sun; for if we imagine the concavity of the Earth's orbit to be measured by the length of a perpendicular line *Cg*, let down from the Earth's place upon the straight line *bgd* at the full of the Moon, and connecting the places of the Earth at the end of the Moon's first and third quarters, that length will be about 640 thousand miles; and the Moon when new only approaching nearer to the Sun by 240 thousand miles than the Earth, is the length of the perpendicular let down from her place at that time upon the same straight line, all which shews that the concavity of that part of her path, will be about 400 thousand miles. PLATE VII.

268. The Moon's path being concave to the Sun throughout, demonstrates that her gravity toward the Sun at her conjunction, exceeds her gravity toward the Earth. And if we consider that the quantity of matter in the Sun is almost 230 thousand times as great as the quantity of matter in the Earth, and that the attraction of each body diminishes as the square of the distance from it increases, we shall soon find, that the point of equal attraction between the Earth and the Sun, is about 70 thousand miles nearer the Earth than the Moon is at her change. It may then appear surprising that the Moon does not abandon the Earth, when she is between it and the Sun, because she is considerably more attracted by the Sun than by the Earth at that time. But this difficulty vanishes when we consider, that a common impulse on any system of bodies affects A difficulty removed.

PLATE VII. not their relative motions; but that they will continue to attract, impel, or circulate round one another, in the same manner as if there were no such impulse. The Moon is so near the Earth, and both of them so far from the Sun, that the attractive power of the Sun may be considered as equal on both: and therefore the Moon will continue to circulate round the Earth nearly in the same manner as if the Sun did not attract them at all. For bodies in the cabin of a ship, may move round, or impel one another in the same manner when the ship is under sail, as when it is at rest; because they are all equally affected by the common motion of the ship. If by any other cause, such as the near approach of a comet, the Moon's distance from the Earth should happen to be so much increased, that the difference of their gravitating forces toward the Sun should exceed that of the Moon toward the Earth; in that case the Moon when in conjunction, would abandon the Earth, and be either drawn into the Sun or comet, or circulate round about it.

Fig. III. 269. The curves which Jupiter's satellites describe, are all of different sorts from the path described by our Moon, although these satellites go round Jupiter as the Moon goes round the Earth. Let *ABCDE*, &c. be as much of Jupiter's orbit as he describes in 18 days from *A* to *T*; and the curves *a*, *b*, *c*, *d*, will be the paths of his four moons going round him in his progressive motion.

The absolute path of Jupiter and his satellites delineated.

Now let us suppose all these moons to set out from a conjunction with the Sun, as seen from Jupiter at *A*; then his first or nearest moon will be at *a*, his second at *b*, his third at *c*, and his fourth at *d*. At the end of 24 terrestrial hours after this conjunction, Jupiter has moved to *B*, his first moon or satellite has described the curve *a* 1, his second the curve *b* 1, his third *c* 1, and his fourth *d* 1. The next day, when Jupiter is at *C*, his first satellite has

described the curve *a* 2, from its conjunction, his second the curve *b* 2, his third the curve *c* 2, and his fourth the curve *d* 2, and so on. The numeral figures under the capital letters shew Jupiter's place in his path every day for 18 days, accounted from *A* to *T*; and the like figures set to the paths of his satellites, shew where they are at the like times. The first satellite, almost under *C*, is stationary at +, as seen from the Sun; and retrograde from + to 2: at 2 it appears stationary again, and thence it moves forward until it has passed 3, and is twice stationary and once retrograde between 3 and 4.— The path of this satellite intersects itself every $42\frac{1}{2}$ hours, making such loops as in the diagram at 2. 3. 5. 7. 9. 10. 12. 14. 16. 18, a little after every conjunction. The second satellite *b*, moving slower, barely crosses its path every 3 days 13 hours; as at 4. 7. 11. 14. 18. making only 5 loops and as many conjunctions in the time that the first makes ten. The third satellite *c*, moving still slower, and having described the curve *c* 1. 2. 3. 4. 5. 6. 7, comes to an angle at 7, in conjunction with the Sun, at the end of 7 days 4 hours; and so goes on to describe such another curve 7. 8. 9. 10. 11. 12. 13. 14, and is at 14 in its next conjunction. The fourth satellite *d* is always progressive, making neither loops nor angles in the heavens; but comes to its next conjunction at *e* between the numeral figures 16 and 17, or in 16 days 18 hours. In order to have a tolerable good figure of the paths of these satellites, I took the following method.

PLATE VII.

Fig. III.

Having drawn their orbits on a card, in proportion to their relative distances from Jupiter, I measured the radius of the orbit of the fourth satellite, which was an inch and $\frac{14}{100}$ parts of an inch; then multiplied this by 424 for the radius of Jupiter's orbit, because Jupiter is 424 times as far from the Sun's centre as his fourth satellite is from his centre, and the product thence arising was $483\frac{36}{100}$,

Fig. IV.

PLATE VII.

How to delineate the paths of Jupiter's Moons,

inches. Then taking a small cord of this length, and fixing one end of it to the floor of a long room by a nail, with a black-lead pencil at the other end I drew the curve *ABCD*, &c. and set off a degree and a half thereon, from *A* to *T*; because Jupiter moves only so much, while his outermost satellite goes once round him, and somewhat more: so that this small portion of so large a circle differs but very little from a straight line. This done I divided the space *A T* into 18 equal parts, as *A B*, *B C*, &c. for the daily progress of Jupiter; and each part into 24 for his hourly progress. The orbit of each satellite was also divided into as many equal parts as the satellite is hours in finishing its synodical period round Jupiter. Then drawing a right line through the centre of the card, as a diameter to all the four orbits upon it, I put the card upon the line of Jupiter's motion, and transferred it to every horary division thereon, keeping always the same diameter-line on the line of Jupiter's path; and running a pin through each horary division in the orbit of each satellite as the card was gradually transferred along the line *ABCD*, &c. of Jupiter's motion, I marked points for every hour through the card for the curves described by the satellites, as the primary planet in the centre of the card was carried forward on the line; and so finished the figure, by drawing the lines of each satellite's motion through those (almost innumerable) points: by which means, this is, perhaps, as true a figure of the paths of these satellites as can be desired. And in the same manner might those of Saturn's satellites be delineated.

and Saturn's.

The grand periods of Jupiter's moons.

270. It appears by the scheme, that the three first satellites come almost into the same line of position every seventh day; the first being only a little behind with the second, and the second behind with the 3d. But the period of the 4th satellite is so incommensurate to the periods of the other three, that it cannot

be guessed at by the diagram when it would fall again into a line of conjunction with them between Jupiter and the Sun. And no wonder; for supposing them all to have been once in conjunction, it will require 3,087,043,493,260 years to bring them in conjunction again. See § 73.

PLATE VII.

Fig. IV. The proportions of the orbits of the planets and satellites.

271. In Fig. 4th, we have the proportions of the orbits of Saturn's five satellites, and of Jupiter's four, to one another, to our Moon's orbit, and to the disc of the Sun. *S* is the Sun; *M m* the Moon's orbit (the Earth supposed to be at *E*); *J* Jupiter; 1. 2. 3. 4, the orbits of his four moons or satellites; *Sat.* Saturn; and 1. 2. 3. 4. 5, the orbits of his five moons. Hence it appears, that the Sun would much more than fill the whole orbit of the Moon; for the Sun's diameter is 763,000 miles, and the diameter of the Moon's orbit only 480,000. In proportion to all these orbits of the satellites, the radius of Saturn's annual orbit would be 21¼ yards, of Jupiter's orbit 11⅔, and of the Earth's 2¼, taking them in round numbers.

272. The annexed table shews at once what proportion the orbits, revolutions, and velocities of all the satellites bear to those of their primary planets, and what sort of curves the several satellites describe. For those satellites, whose velocities round their primaries are greater than the velocities of their primaries in open space, make loops at their conjunctions, § 269; appearing retrograde as seen from the Sun while they describe the inferior parts of their orbits, and direct while they describe the superior. This is the case with Jupiter's first and second satellites, and with Saturn's first. But those satellites, whose velocities are less than the velocities of their primary planets, move direct in their whole circumvolutions; which is the case of the third and fourth satellites of Jupiter, and of the second, third, fourth, and fifth satellites of Saturn, as well as of our satellite the Moon: but the Moon is the only satellite whose motion is always concave to the Sun.

The Satellites		Proportion of the Radius of the Planet's Orbit to the Radius of the Orbit of each Satellite.	Proportion of the Time of the Planet's Revolution to the Revolution of each Satellite.	Proportion of the Velocity of each Satellite to the Velocity of its primary Planet.
of Saturn	1	As 5322 to 1	As 5738 to 1	As 5738 to 5322
	2	4155 1	3912 1	3912 4155
	3	2954 1	2347 1	2347 2954
	4	1295 1	674 1	674 1295
	5	432 1	134 1	134 432
of Jupiter	1	As 1851 to 1	As 2445 to 1	As 2445 to 1851
	2	1165 1	1219 1	1219 1165
	3	731 1	604 1	604 731
	4	424 1	258 1	258 424
The Moon		As 337½ to 1	As 12⅓ to 1	As 12⅓ to 337½

There is a table of this sort in *De la Caille's* Astronomy, but it is very different from the above, which I have computed from our *English* accounts of the periods and distances of these planets and satellites.

CHAP. XVI.

The Phenomena of the Harvest-Moon explained by a common Globe. The Years in which the Harvest Moons are least and most beneficial from 1751 *to* 1861. *The long Duration of Moon-light at the Poles in Winter.*

273. IT is generally believed that the Moon rises about 50 minutes later every day than on the preceding: but this is true only with regard to places on the equator. In places of considerable latitude there is a remarkable difference, especially in the harvest time, with which farmers were better acquainted than astronomers, till of late; and gratefully ascribed the early rising of the full moon at that time of the year to the goodness of God, not doubting that he had ordered it so on purpose to give them an immediate supply of moon-light after sun-set, for their greater conveniency in reaping the fruits of the Earth. **No Harvest-moon at the equator:**

In this instance of the harvest-moon, as in many others discoverable by astronomy, the wisdom and beneficence of the Deity is conspicuous, who really ordered the course of the Moon so, as to bestow more or less light on all parts of the Earth as their several circumstances and seasons render it more or less serviceable. About the equator, where there is no variety of seasons, and the weather changes seldom, and at stated times, moon-light is not necessary for gathering in the produce of the ground, and there the Moon rises about 50 minutes later every day or night than on the former. At considerable distances from the equator, where the weather and seasons are more uncertain, the autumnal full Moon rises very soon after sun-set for several evenings to

But remarkable according to the distances of places from it.

gether. At the polar circles, where the mild season is of very short duration, the autumnal full Moon rises at sun-set from the first to the third quarter. And at the poles, where the Sun is for half a year absent, the winter full Moons shine constantly without setting from the first to the third quarter.

The reason of this.

It is soon said that all these phenomena are owing to the different angles made by the horizon and different parts of the Moon's orbit; and that the Moon can be full but once or twice in a year in those parts of her orbit which rise with the least angles. But to explain this subject intelligibly, we must dwell much longer upon it.

274. The* plane of the equinoctial is perpendicular to the Earth's axis; and therefore, as the Earth turns round its axis, all parts of the equinoctial make equal angles with the horizon both at rising and setting; so that equal portions of it always rise or set in equal times. Consequently, if the Moon's motion were equable, and in the equinoctial, at the rate of 12 degrees 11 min. from the Sun every day, as it is in her orbit, she would rise and set 50 minutes later every day than on the preceding; for 12 deg. 11 min. of the equinoctial, rise or set in 50 minutes of time in all latitudes.

275. But the Moon's motion is so nearly in the ecliptic, that we may consider her at present as moving in it. Now the different parts of the ecliptic, on account of its obliquity to the Earth's axis, make very different angles with the horizon as they rise or set. Those parts or signs which rise with the smallest angles set with the greatest, and *vice versa*. In equal times, whenever this angle is least, a greater portion of the ecliptic rises than when the angle is larger; as may be seen by elevating the pole of a globe to any considerable latitude, and then

* If a globe be cut quite through upon any circle, the flat surface where it is so divided is the *plane* of that circle.

turning it round its axis. Consequently, when the Moon is in those signs which rise or set with the smallest angles, she rises or sets with the least difference of time; and with the greatest difference in those signs which rise or set with the greatest angles. PLATE III Fig. III

But, because all who read this treatise may not be provided with globes, though in this case it is requisite to know how to use them, we shall substitute the figure of a globe; in which *FUP* is the axis, ♋ *TR* the tropic of Cancer, *Lt* ♑ the tropic of Capricorn, ♋ *EU* ♑ the ecliptic touching both the tropics, which are 47 degrees from each other, and *AB* the horizon. The equator being in the middle between the tropics, is cut by the ecliptic in two opposite points, which are the beginnings of ♈ Aries and ♎ Libra; *K* is the hour-circle with its index, *F* the north pole of the globe elevated to a considerable latitude, suppose 40 degrees above the horizon; and *P* the south pole depressed as much below it. Because of the oblique position of the sphere in this latitude, the ecliptic has the high elevation *N* ♋ above the horizon, making the angle *NU* ♋ of 73½ degrees with it when ♋ Cancer is on the meridian, at which time ♎ Libra rises in the east. But let the globe be turned half round its axis, till ♑ Capricorn comes to the meridian and ♈ Aries rises in the east, and then the ecliptic will have the low elevation *NL* above the horizon, making only an angle *NUL* of 26½ degrees with it; which is 47 degrees less than the former angle, equal to the distance between the tropics. Fig. III. The different angles made by the ecliptic and horizon.

276. In northern latitudes, the smallest angle made by the ecliptic and horizon is when Aries rises, at which time Libra sets; the greatest when Libra rises, at which time Aries sets. From the rising of Aries to the rising of Libra (which is twelve* side- Least and greatest, when.

* The ecliptic, together with the fixed stars, make 366¼ apparent diurnal revolutions about the Earth in a year; the Sun only 365¼. Therefore the stars gain 3 minutes 56 se-

ral hours) the angle increases; and from the rising of Libra to the rising of Aries, it decreases in the same proportion. By this article and the preceding it appears that the ecliptic rises fastest about Aries, and slowest about Libra.

Result of the quantity of this angle at London.

277. On the parallel of *London*, as much of the ecliptic rises about Pisces and Aries in two hours as the Moon goes through in six days: and therefore while the Moon is in these signs, she differs but two hours in rising for six days together; that is, about 20 minutes later every day or night than on the preceding, at a mean rate. But in fourteen days afterward, the Moon comes to Virgo and Libra, which are the opposite signs to Pisces and Aries; and then she differs almost four times as much in rising; namely, one hour and about fifteen minutes later every day or night than the former, while she is in these signs. The annexed table shews the daily mean difference of the Moon's rising and setting on the parallel of *London*, for 28 days; in which time the moon finishes her

Days.	Signs.	Degrees	Rising Diff.		Setting Diff.	
			H.	M.	H.	M.
1	♋	13	1	5	0	50
2		26	1	10	0	43
3	♌	10	1	14	0	37
4		23	1	17	0	32
5	♍	6	1	16	0	28
6		19	1	15	0	24
7	♎	2	1	15	0	20
8		15	1	15	0	18
9		28	1	15	0	17
10	♏	12	1	15	0	22
11		25	1	14	0	30
12	♐	8	1	13	0	39
13		21	1	10	0	47
14	♑	4	1	4	0	56
15		17	0	46	1	5
16	♒	1	0	40	1	8
17		14	0	35	1	12
18		27	0	30	1	15
19	♓	10	0	25	1	16
20		23	0	20	1	17
21	♈	7	0	17	1	16
22		20	0	17	1	15
23	♉	3	0	20	1	11
24		16	0	24	1	15
25		29	0	30	1	14
26	♊	13	0	40	1	13
27		26	0	56	1	7
28	♋	9	1	00	0	58

conds upon the Sun every day; so that a sideral day contains only 23 hours 56 minutes of mean solar time; and a natural or solar day 24 hours. Hence 12 sideral hours are one minute 58 seconds shorter than 12 solar hours.

period round the ecliptic, and gets 9 degrees into the same sign from the beginning of which she set out. Thus it appears by the table, that when the Moon is in ♍ and ♎ she rises an hour and a quarter later every day than she rose on the former; and differs only 28, 24, 20, 18 or 17 minutes in setting. But, when she comes to ♓ and ♈, she is only 20 or 17 minutes later in rising; and an hour and a quarter later in setting. PLATE III

278. All these things will be made plain by putting small patches on the ecliptic of a globe, as far from one another as the Moon moves from any point of the celestial ecliptic in 24 hours, which at a mean rate is* $13\frac{1}{8}$ degrees; and then, in turning the globe round, observe the rising and setting of the patches in the horizon, as the index points out the different times on the hour-circle. A few of these patches are represented by dots at 0 1 2 3, &c. on the ecliptic, which has the position *LUI* when Aries rises in the east; and by the dots 0 1 2 3, &c. when Libra rises in the east, at which time the ecliptic has the position *EU*♑: making an angle of 62 degrees with the horizon in the latter case, and an angle of no more than 15 degrees with it in the former; supposing the globe rectified to the latitude of *London*. Fig. III.

279. Having rectified the globe, turn it until the patch at 0, about the beginning of ♓ Pisces in the half *LUI* of the ecliptic, comes to the eastern side of the horizon, and then, keeping the ball steady, set the hour-index to XII, because *that* hour may perhaps be more easily remembered than any other. Then turn the globe round westward, and in that time, suppose the patch 0 to have moved thence

* The Sun advances almost a degree in the ecliptic in 24 hours, the same way that the Moon moves; and therefore the Moon by advancing $13\frac{1}{8}$ degrees in that time, goes little more than 12 degrees farther from the Sun than she was on the day before

to 1, 13⅓ degrees, while the Earth turns once round its axis, and you will see that 1 rises only about 20 minutes later than 0 did on the day before. Turn the globe round again, and in that time suppose the same patch to have moved from 1 to 2; and it will rise only 20 minutes later by the hour-index than it did at 1 on the day or turn before. At the end of the next turn suppose the patch to have gone from 2 to 3 at *U*, and it will rise 20 minutes later than it did at 2, and so on for six turns, in which time there will scarce be two hours difference, nor would there have been so much, if the 6 degrees of the Sun's motion in that time had been allowed for. At the first turn the patch rises south of the east, at the middle turn due east, and at the last turn north of the east. But these patches will be 9 hours in setting on the western side of the horizon, which shews that the Moon's setting will be so much retarded in that week in which she moves through these two signs. The cause of this difference is evident; for Pisces and Aries make only an angle of 15 degrees with the horizon when they rise; but they make an angle of 62 degrees with it when they set. As the signs Taurus, Gemini, Cancer, Leo, Virgo, and Libra, rise successively, the angle increases gradually which they make with the horizon, and decreases in the same proportion as they set. And for that reason, the Moon differs gradually more in the time of her rising every day while she is in these signs, and less in her setting: after which, through the other six signs, *viz.* Scorpio, Sagittary, Capricorn, Aquarius, Pisces, and Aries, the rising-difference becomes less every day, until it be at the least of all, namely, in Pisces and Aries.

280. The Moon goes round the ecliptic in 27 days 8 hours: but not from change to change in less than 29 days 12 hours: so that she is in Pisces and Aries at least once in every lunation, and in some lunations twice.

281. If the Earth had no annual motion, the Sun would never appear to shift his place in the ecliptic. And then every new Moon would fall in the same sign and degree of the ecliptic, and every full Moon in the opposite: for the Moon would go precisely round the ecliptic from change to change. So that if the Moon were once full in Pisces or Aries, she would always be full when she came round to the same sign and degree again. And as the full Moon rises at sun-set (because when any point of the ecliptic sets, the opposite point rises) she would constantly rise within two hours of sun-set, on the parallel of *London*, during the week in which she was full. But in the time that the Moon goes round the ecliptic from any conjunction or opposition, the Earth goes almost a sign forward: and therefore the Sun will seem to go as far forward in that time, namely, $27\frac{1}{2}$ degrees; so that the Moon must go $27\frac{1}{2}$ degrees more than round, and as much farther as the Sun advances in that interval, which is $2\frac{1}{16}$ degrees, before she can be in conjunction with, or opposite to the Sun again. Hence it is evident that there can be but one conjunction or opposition of the Sun and Moon in a year in any particular part of the ecliptic. This may be familiarly exemplified by the hour and minute-hands of a watch, which are never in conjunction or opposition in that part of the dial-plate where they were so last before. And indeed if we compare the twelve hours on the dial-plate to the twelve signs of the ecliptic, the hour-hand to the Sun, and the minute-hand to the Moon, we shall have a tolerable near resemblance in miniature to the motions of our great celestial luminaries. The only difference is, that while the Sun goes once round the ecliptic, the Moon makes $12\frac{1}{3}$ conjunctions with him: but, while the hour-hand goes round the dial-plate, the minute-hand makes only 11 conjunctions with it; because the minute-hand moves slower in respect to the hour-

Why the Moon is always full in different signs.

Her periodical and synodical revolution exemplified.

Hh

hand than the Moon does with regard to the Sun.

The harvest and hunter's Moon.

282. As the Moon can never be full but when she is opposite to the Sun, and the Sun is never in Virgo and Libra, but in our autumnal months, it is plain that the Moon is never full in the opposite signs, Pisces and Aries, but in these two months. And therefore we can have only two full Moons in the year, which rise so near the time of sun-set for a week together, as above-mentioned. The former of these is called the *Harvest Moon*, and the latter the *Hunter's Moon*.

Why the Moon's regular rising is never perceived but in harvest.

283. Here it will probably be asked, why we never observe this remarkable rising of the Moon but in harvest, seeing she is in Pisces and Aries twelve times in the year besides; and must then rise with as little difference of time as in harvest? The answer is plain: for in winter these signs rise at noon; and being then only a quarter of a circle distant from the Sun, the Moon in them is in her first quarter: but when the Sun is above the horizon, the Moon's rising is neither regarded nor perceived. In spring these signs rise with the Sun, because he is then in them; and as the Moon changes in them at that time of the year, she is quite invisible. In summer they rise about midnight, and the Sun being then three signs, or a quarter of a circle before them, the Moon is in them about her third quarter; and when rising so late, and giving but very little light, her rising passes unobserved. And in autumn these signs, being opposite to the Sun, rise when he sets, with the Moon in opposition, or at the full, which makes her rising very conspicuous.

284. At the equator, the north and south poles lie in the horizon, and therefore the ecliptic makes the same angle southward with the horizon, when Aries rises, as it does northward when Libra rises. Consequently as the Moon at all the fore-mentioned parcels rises and sets nearly at equal angles with the horizon

all the year round, and about 50 minutes later every day or night than on the preceding, there can be no particular harvest-moon at the equator.

285. The farther that any place is from the equator, if it be not beyond the polar circle, the angle gradually diminishes which the ecliptic and horizon make when Pisces and Aries rise: and therefore when the Moon is in these signs she rises with a nearly proportionable difference later every day than on the former; and is for that reason the more remarkable about the full, until we come to the polar circles, or 66 degrees from the equator; in which latitude the ecliptic and horizon become coincident every day for a moment, at the same sidereal hour (or 3 minutes 56 seconds sooner every day than the former), and the very next moment one half of the ecliptic, containing Capricorn, Aquarius, Pisces, Aries, Taurus, and Gemini, rises, and the opposite half sets. Therefore, while the Moon is going from the beginning of Capricorn to the beginning of Cancer, which is almost 14 days, she rises at the same sidereal hour; and in autumn just at sun-set, because all the half of the ecliptic, in which the Sun is at that time, sets at the same sidereal hour, and the opposite half rises; that is, 3 minutes 56 seconds of mean solar time, sooner every day than on the day before. So while the Moon is going from Capricorn to Cancer, she rises earlier every day than on the preceding; contrary to what she does at all places between the polar circles. But during the above fourteen days, the Moon is 24 sidereal hours later in setting; for the six signs which rise all at once on the eastern side of the horizon are 24 hours in setting on the western side of it; as any one may see by making chalk-marks at the beginning of Capricorn and of Cancer, and then, having elevated the pole 66½ degrees, turn the globe slowly round its axis, and observe the rising and setting of the ecliptic. As the beginning of Aries

is equally distant from the beginning of Cancer and of Capricorn, it is in the middle of that half of the ecliptic which rises all at once. And when the Sun is at the beginning of Libra, he is in the middle of the other half. Therefore, when the Sun is in Libra, and the Moon in Capricorn, the Moon is a quarter of a circle before the Sun; opposite to him, and consequently full in Aries, and a quarter of a circle behind him, when in Cancer. But when Libra rises, Aries sets, and all that half of the ecliptic of which Aries is the middle, and therefore, at that time of the year, the Moon rises at sun-set from her first to her third quarter.

The harvest-moons regular on both sides of the equator.

286. In northern latitudes, the autumnal full Moons are in Pisces and Aries; and the vernal full Moons in Virgo and Libra: in southern latitudes, just the reverse, because the seasons are contrary. But Virgo and Libra rise at as small angles with the horizon in southern latitudes, as Pisces and Aries do in the northern; and therefore the harvest-moons are just as regular on one side of the equator as on the other.

287. As these signs, which rise with the least angles, set with the greatest, the vernal full Moons differ as much in their times of rising every night, as the autumnal full Moons differ in their times of setting; and set with as little difference as the autumnal full Moons rise: the one being in all cases the reverse of the other.

288. Hitherto, for the sake of plainness, we have supposed the Moon to move in the ecliptic, from which the Sun never deviates. But the orbit in which the Moon really moves is different from the ecliptic: one half being elevated $5\frac{1}{3}$ degrees above it, and the other half as much depressed below it. The Moon's orbit therefore intersects the ecliptic in two points diametrically opposite to each other; and these intersections are called the *Moon's nodes*. So the Moon can never be in the ecliptic

but when she is in either of her nodes, which is at least twice in every course from change to change, and sometimes thrice. For, as the Moon goes almost a whole sign more than round her orbit from change to change; if she passes by either node about the time of change, she will pass by the other in about fourteen days after, and come round to the former node two days again before the next change. That node from which the Moon begins to ascend northward, or above the ecliptic, in northern latitudes, is called the *ascending node;* and the other the *descending node;* because the Moon, when she passes by it, descends below the ecliptic southward. The Moon's nodes

289. The Moon's oblique motion with regard to the ecliptic causes some difference in the times of her rising and setting from what is already mentioned. For when she is northward of the ecliptic, she rises sooner and sets later than if she moved in the ecliptic; and when she is southward of the ecliptic, she rises later and sets sooner. This difference is variable even in the same signs, because the nodes shift backward about $19\frac{1}{3}$ degrees in the ecliptic every year; and so go round it contrary to the order of signs in 18 years 225 days.

290. When the ascending node is in Aries, the southern half of the Moon's orbit makes an angle of $5\frac{1}{3}$ degrees less with the horizon than the ecliptic does, when Aries rises in northern latitudes: for which reason the Moon rises with less difference of time while she is in Pisces and Aries, than she would do if she kept in the ecliptic. But in 9 years and 112 days afterward, the descending node comes to Aries; and then the Moon's orbit makes an angle $5\frac{1}{3}$ degrees greater with the horizon when Aries rises, than the ecliptic does at that time; which causes the Moon to rise with greater difference of time in Pisces and Aries than if she moved in the ecliptic.

291. To be a little more particular, when the ascending node is in Aries, the angle is only $9\frac{2}{3}$ degrees on the parallel of *London* when Aries rises. But when the descending node comes to Aries, the angle is $20\frac{1}{3}$ degrees; this occasions as great a difference of the Moon's rising in the same signs every nine years, as there would be on two parallels $10\frac{2}{3}$ degrees from one another, if the Moon's course were in the ecliptic. The following table shews how much the obliquity of the Moon's orbit affects her rising and setting on the parallel of *London*, from the 12th to the 18th day of her age; supposing her to be full at the autumnal equinox: and then, either in the ascending node, highest part of her orbit, descending node, or lowest part of her orbit. *M* signifies morning, *A* afternoon: and the line at the foot of the table shews a week's difference in rising and setting.

Moon's Age	Full in her Ascending Node		In the highest pt. of her Orbit.		Full in her Descending Node.		In the lowest pt. of her Orbit.	
	Rises at H. M.	Sets at H. M.	Rises at H. M.	Sets at H. M.	Rises at H. M.	Sets at H. M.	Rises at H. M.	Sets at H. M.
12	5 *A* 15	3 *M* 0	4 *A* 36	3 *M* 15	4 *A* 32	3 *M* 40	5 *A* 10	3 *M* 0
13	5 34	4 25	4 50	4 45	5 13	4 20	6 0	4 15
14	5 48	5 30	5 15	6 0	5 43	5 40	6 20	5 28
15	6 5	7 0	5 44	7 20	6 15	6 56	6 45	6 32
16	6 20	8 15	6 2	8 35	6 40	8 0	7 6	7 45
17	6 36	9 12	6 26	9 45	7 18	9 1[illegible]	7 30	9 15
18	6 54	10 30	7 0	10 40	9 0	10 20	7 5	10 0
Diff.	1 39	7 10	2 30	7 25	3 28	6 40	[illegible] 36	7 0

This table was not computed, but only estimated as near as could be done from a common globe, on which the Moon's orbit was delineated with a black-lead pencil. It may at first sight appear erroneous, since as we have supposed the Moon to be full in either node at the autumnal equinox, ought by the

table to rise just at six o'clock, or at sun-set, on the 15thday of her age; being in the ecliptic at that time. But it must be considered, that the Moon is only 14¾ days old when she is full; and therefore in both cases she is a little past the node on the 15th day, being above it at one time, and below it at the other.

292. As there is a complete revolution of the nodes in 18⅔ years, there must be a regular period of all the varieties which can happen in the rising and setting of the Moon during that time. But this shifting of the nodes never affects the Moon's rising so much, even in her quickest descending latitude, as not to allow us still the benefit of her rising nearer the time of sun-set for a few day together about the full in harvest, than when she is full at any other time of the year. The following table shews in what years the harvest-moons are least beneficial as to the times of their rising, and in what years most, from 1751 to 1861. The column of years under the letter *L* are those in which the harvest-moons are least of all beneficial, because they fall about the descending node: and those under *M* are the most of all beneficial, because they fall about the ascending node. In all the columns from *N* to *S* the harvest-moons descend gradually in the lunar orbit, and rise to less heights above the horizon. From *S* to *N* they ascend in the same proportion, and rise to greater heights above the horizon. In both the columns under *S*, the harvest-moons are in the lowest part of the Moon's orbit, that is, farthest south of the ecliptic, and therefore stay shortest of all above the horizon: in the columns under *N*, just the reverse. And in both cases, their risings, though not at the same times, are nearly the same with regard to difference of time, as if the Moon's orbit were coincident with the ecliptic. The period of the harvest-moon.

Years in which the Harvest-Moons are least beneficial.

N					L			S	
1751	1752	1753	1754	1755	1756	1757	1758	1759	
1770	1771	1772	1773	1774	1775	1776	1777	1778	
1788	1789	1790	1791	1792	1793	1794	1795	1796	1797
1807	1808	1809	1810	1811	1812	1813	1814	1815	
1826	1827	1828	1829	1830	1831	1832	1833	1834	
1844	1845	1846	1847	1848	1849	1850	1851	1852	

Years in which they are most beneficial.

S				M				N	
1760	1761	1762	1763	1764	1765	1766	1767	1768	1769
1779	1780	1781	1782	1783	1784	1785	1786	1787	
1798	1799	1800	1801	1802	1803	1804	1805	1806	
1816	1817	1818	1819	1820	1821	1822	1823	1824	1825
1835	1836	1837	1838	1839	1840	1841	1842	1843	
1853	1854	1855	1856	1857	1858	[illegible]	1860	1861	

293. At the polar circles, when the Sun touches the summer-tropic, he continues 24 hours above the horizon; and 24 hours below it when he touches the winter-tropic. For the same reason the full Moon neither rises in summer, nor sets in winter, considering her as moving in the ecliptic. For the winter full Moon being as high in the ecliptic as the summer Sun, must therefore continue as long above the horizon; and the summer full Moon being as low in the ecliptic as the winter Sun, can no more rise than he does. But these are only the two full Moons which happen about the tropics, for all the others rise and set. In summer the full Moons are low, and their stay is short above the horizon, when the nights are short, and we have least occasion for moon-light: in winter they go high, and stay long above the horizon, when the nights are long, and we want the greatest quantity of moon-light.

The long continuance of moon-light at the poles.

294. At the poles, one half of the ecliptic never sets, and the other half never rises: and therefore, as the Sun is always half a year in describing one half of the ecliptic, and as long in going through

the other half, it is natural to imagine that the Sun continues half a year together above the horizon of each pole in its turn, and as long below it; rising to one pole when he sets to the other. This would be exactly the case if there were no refraction; but by the atmosphere's refracting the Sun's rays, he becomes visible some days sooner, § 183, and continues some days longer in sight than he would otherwise do: so that he appears above the horizon of either pole before he has got below the horizon of the other. And, as he never goes more than 23½ degrees below the horizon of the poles, they have very little dark night; it being twilight there as well as at all other places, till the Sun is 18 degrees below the horizon, § 177. The full Moon being always opposite to the Sun, can never be seen while the Sun is above the horizon, except when the Moon fulls in the northern half of her orbit; for whenever any point of the ecliptic rises, the opposite point sets. Therefore, as the Sun is above the horizon of the north pole from the 20th of *March* till the 23d of *September*, it is plain that the Moon, when full, being opposite to the Sun, must be below the horizon during that half of the year. But when the Sun is in the southern half of the ecliptic, he never rises to the north pole, during which half of the year, every full Moon happens in some part of the northern half of the ecliptic, which never sets. Consequently, as the polar inhabitants never see the full Moon in summer, they have her always in the winter, before, at, and after the full, shining for 14 of our days and nights. And when the Sun is at his greatest depression below the horizon, being then in Capricorn, the Moon is at her first quarter in Aries, full in Cancer, and at her third quarter in Libra. And as the beginning of Aries is the rising point of the ecliptic, Cancer the highest, and Libra the setting point, the Moon rises at her first quarter in Aries, is most elevated above the horizon, and full in Cancer, and sets at the beginning of Libra in her third

PLATE VIII. quarter, having continued visible for 14 diurnal rotations of the Earth. Thus the poles are supplied one half of the winter-time with constant moon-light in the Sun's absence; and only lose sight of the Moon from her third to her first quarter, while she gives but very little light, and could be but of little, and sometimes of no service to them. A bare view of the figure will make this plain: in which let *S* be the Sun, *e* the Earth in summer, when its north pole *n* inclines toward the Sun, and *E* the Earth in winter, when its north pole declines from him. *SEN* and *NWS* is the horizon of the north pole, which is coincident with the equator; and, in both these positions of the Earth, ♈ ♋ ♎ ♑ is the Moon's orbit, in which she goes round the Earth, according to the order of the letters *a b c d*, *ABCD*. When the Moon is at *a*, she is in her third quarter to the Earth at *e*, and just rising to the north pole *n*; at *b* she changes, and is at the greatest height above the horizon, as the Sun likewise is; at *c* she is in her first quarter, setting below the horizon; and is lowest of all under it at *d*, when opposite to the Sun, and her enlightened side toward the Earth. But then she is full in view to the south pole *p*; which is as much turned from the Sun as the north pole inclines toward him. Thus in our summer, the Moon is above the horizon of the north pole, while she describes the northern half of the ecliptic ♈ ♋ ♎, or from her third quarter to her first; and below the horizon during her progress through the southern half ♎ ♑ ♈; highest at the change, most depressed at the full. But in winter, when the Earth is at *E*, and its north pole declines from the Sun, the new Moon at *D* is at her greatest depression below the horizon *NWS*, and the full Moon at *B* at her greatest height above it; rising at her first quarter *A*, and keeping above the horizon till she comes to her third quarter *C*. At a mean state she is $23\frac{1}{2}$ degrees above the horizon at *B* and *b*, and as much below it at *D* and *d*, equal to the inclination

Fig. V.

of the Earth's axis *F*. *S* ♋ or *S* ♑ is, as it were, a ray of light proceeding from the Sun to the Earth; and shews that when the Earth is at *e*, the Sun is above the horizon, vertical to the tropic of Cancer; and when the Earth is at *E*, he is below the horizon, vertical to the tropic of Capricorn.

CHAP. XVII.

Of the Ebbing and Flowing of the Sea.

The cause of the tides discovered by KEPLER.

295. THE cause of the tides was discovered by KEPLER, who, in his *Introduction to the Physics of the Heavens*, thus explains it: "The orb of the attracting power, which is in the Moon, is extended as far as the Earth; and draws the waters under the torrid zone, acting upon places where it is vertical, insensibly on confined seas and bays, but sensibly on the ocean, whose beds are large, and the waters have the liberty of reciprocation; that is, of rising and falling." And in the 70th page of his *Lunar Astronomy*—"But the cause of the tides of the sea appears to be the bodies of the Sun and Moon drawing the waters of the sea."—This hint being given, the immortal Sir ISAAC NEWTON improved it, and wrote so amply on the subject, as to make the theory of the tides in a manner quite his own; by discovering the cause of their rising on the side of the Earth opposite to the Moon. For KEPLER believed, that the presence of the Moon occasioned an impulse which caused another in her absence.

Their theory improved by Sir ISAAC NEWTON.

Explained on the New[illegible] [illegible] P[illegible] Fi[illegible]

296. It has been already shewn, § 106, that the power of gravity diminishes as the square of the distance increases; and therefore the waters at Z, on the side of the Earth *ABCDEFGH* next the Moon *M*, are more attracted than the central parts of the Earth *O* by the Moon, and the central parts are more attracted by her than the waters on the opposite side of the Earth at *n*: and there-

PLATE IX. fore the distance between the Earth's centre and the waters on its surface under and opposite to the Moon will be increased. For, let there be three bodies at *H*, *O*, and *D*: if they be all equally attracted by the body *M*, they will all move equally fast toward it, their mutual distances from each other continuing the same. If the attraction of *M* be unequal, then that body which is most strongly attracted will move fastest, and this will increase its distance from the other body. Therefore, by the law of gravitation, *M* will attract *H* more strongly than it does *O*, by which the distance between *H* and *O* will be increased: and a spectator on *O* will perceive *H* rising higher toward *Z*. In like manner, *O* being more strongly attracted than *D*, it will move farther toward *M* than *D* does: consequently, the distance between *O* and *D* will be increased; and a spectator on *O*, not perceiving his own motion, will see *D* receding farther from him toward *n*: all effects and appearances being the same, whether *D* recedes from *O*, or *O* from *D*.

297. Suppose now there is a number of bodies, as *A*, *B*, *C*, *D*, *E*, *F*, *G*, *H*, placed round *O*, so as to form a flexible or fluid ring: then, as the whole is attracted towards *M*, the parts at *H* and *D* will have their distance from *O* increased; while the parts at *B* and *F*, being nearly at the same distance from *M* as *O* is, these parts will not recede from one another; but rather, by the oblique attraction of *M*, they will approach nearer to *O*. Hence, the fluid ring will form itself into an ellipse *Z I B L n K F N Z*, whose longer axis *n O Z* produced will pass through *M*, and its shorter axis *B O F* will terminate in *B* and *F*. Let the ring be filled with fluid particles, so as to form a sphere round *O*; then, as the whole moves toward *M*, the fluid sphere being lengthened at *Z* and *n*, will assume an oblong or oval form. If *M* be the Moon, *O* the Earth's centre, *ABCDEFGH* the sea covering the

Earth's surface, it is evident, by the above reasoning, that while the Earth by its gravity falls toward the Moon, the water directly below her at *B* will swell and rise gradually toward her: also the water at *D* will recede from the centre (strictly speaking, the centre recedes from *D*), and rise on the opposite side of the Earth: while the water at *B* and *F* is depressed, and falls below the former level. Hence, as the Earth turns round its axis from the Moon to the Moon again, in $24\frac{3}{4}$ hours, there will be two tides of flood and two of ebb in that time, as we find by experience. PLATE IX.

298. As this explanation of the ebbing and flowing of the sea, is deduced from the Earth's constantly falling toward the Moon by the power of gravity, some may find a difficulty in conceiving how this is possible, when the Moon is full, or in opposition to the Sun; since the Earth revolves about the Sun, and must continually fall toward it, and therefore cannot fall contrary ways at the same time: or, if the Earth be constantly falling toward the Moon, they must come together at last. To remove this difficulty, let it be considered, that it is not the centre of the Earth that describes the annual orbit round the Sun, but the* common centre of gravity of the Earth and Moon together: and that while the Earth is moving round the Sun, it also describes a circle round that centre of gravity; going as many times round it in one revolution about the Sun as there are lunations or courses of the Moon round the Earth in a year: and therefore, the Earth is constantly falling toward the Moon from a tangent to the circle it describes round the said common centre of gravity. Let *M* be the Moon, *T W* part of

* This centre is as much nearer the Earth's centre than the Moon's, as the Earth is heavier, or contains a greater quantity of matter than the Moon, namely, about 40 times. If both bodies were suspended on it, they would hang *in equilibrio*. So that dividing 240,000 miles, the Moon's distance from the Earth's centre, by 40, the excess of the Earth's weight above the Moon's, the quotient will be 6000 miles, which is the distance of the common centre of gravity of the Earth and Moon from the Earth's centre.

PLATE IX. the Moon's orbit, and C the centre of gravity of the Earth and Moon; while the Moon goes round her orbit, the centre of the Earth describes the circle $d\,g\,e$ round C, to which circle $g\,a\,k$ is a tangent: and therefore, when the Moon has gone from M to a little past W, the Earth has moved from g to e; and in that time has fallen toward the Moon, from the tangent at a to e; and so on, round the whole circle.

Fig. II.

299. The Sun's influence in raising the tides is but small in comparison of the Moon's; for though the Earth's diameter bears a considerable proportion to its distance from the Moon, it is next to nothing when compared to its distance from the Sun. And therefore, the difference of the Sun's attraction on the sides of the Earth under and opposite to him, is much less than the difference of the Moon's attraction on the sides of the Earth under and opposite to her: and therefore the Moon must raise the tides much higher than they can be raised by the Sun.

Why the tides are not highest when the Moon is on the meridian

300. On this theory, so far as we have explained it, the tides ought to be highest directly under and opposite to the Moon; that is, when the Moon is due north and south. But we find, that in open seas, where the water flows freely, the Moon M is generally past the north and south meridian, as at p, when it is high water at Z and at n. The reason is obvious; for though the Moon's attraction were to cease altogether when she was past the meridian, yet the motion of ascent communicated to the water before that time would make it continue to rise for some time after; much more must it do so when the attraction is only diminished: as a little impulse given to a moving ball will cause it still to move farther than otherwise it could have done. And as experience shews, that the day is hotter about three in

Fig. I.

the afternoon than when the Sun is on the meridian, because of the increase made to the heat already imparted. PLATE IX.

301. The tides answer not always to the same distance of the Moon from the meridian at the same places; but are variously affected by the action of the Sun, which brings them on sooner when the Moon is in her first and third quarters, and keeps them back later when she is in her second and fourth: because, in the former case, the tide raised by the Sun alone would be earlier than the tide raised by the Moon; and in the latter case later.

Nor always answer to her being at the same distance from it.

302. The Moon goes round the Earth in an elliptic orbit, and therefore, in every lunar month, she approaches nearer to the Earth than her mean distance, and recedes farther from it. When she is nearest, she attracts strongest, and so raises the tides most; the contrary happens when she is farthest, because of her weaker attraction. When both luminaries are in the equator, and the Moon in *perigeo*, or at her least distance from the Earth, she raises the tides highest of all, especially at her conjunction and opposition; both because the equatorial parts have the greatest centrifugal force from their describing the largest circle, and from the concurring actions of the Sun and Moon. At the change, the attractive forces of the Sun and Moon being united, they diminish the gravity of the waters under the Moon, and their gravity on the opposite side is diminished by means of a greater centrifugal force. At the full, while the Moon raises the tide under and opposite to her, the Sun, acting in the same line, raises the tide under and opposite to him; whence their conjoint effect is the same as at the change; and in both cases, occasion what we call the *spring tides*. But at the quarters the Sun's action on the waters at *O* and *H* diminishes the effect of the Moon's action on the waters at *Z* and *N*; so that they rise a little under and opposite to the Sun at *O* and *H*, and fall as-

Spring and neap tides.

Fig. VI.

much under and opposite to the Moon at *Z* and *N*; making what we call the *neap tides*, because the Sun and Moon then act cross-wise to each other. But, strictly speaking, these tides happen not till some time after; because in this, as in other cases, § 300, the actions do not produce the greastet effect when they are at the strongest, but some time afterward.

Not greatest at the equinoxes, and why.

303. The Sun being nearer the Earth in winter than in summer, § 205, is of course nearer to it in *February* and *October*, than in *March* and *September*; and therefore the greatest tides happen not till some time after the autumnal equinox, and return a little before the vernal.

The tides would not immediately cease upon the annihilation of the Sun and Moon.

The sea being thus put in motion, would continue to ebb and flow for several times, even though the Sun and Moon were annihilated, or their influence should cease: as if a bason of water were agitated, the water would continue to move for some time after the bason was left to stand still. Or like a pendulum, which, having been put in motion by the hand, continues to make several vibrations without any new impulse.

The lunar day, what. The tides rise to unequal heights in the same day, and why.

304. When the Moon is in the equator, the tides are equally high in both parts of the lunar day, or time of the Moon's revolving from the meridian to the meridian again, which is 24 hours 50 minutes. But as the Moon declines from the equator toward either pole, the tides are alternately higher and lower at places having north or south latitude. For one of the highest elevations, which is that under the Moon, follows her toward the pole to which she is nearest, and the other declines toward the opposite pole; each elevation describing parallels as far distant from the equator, on opposite sides, as the Moon declines from it to either side; and consequently, the parallels described by these elevations of the water are twice as many degrees from one another, as the Moon is from the equator; increasing their distance as the Moon

increases her declination, till it be at the greatest, when the said parallels are, at a mean state, 47 degrees from one another: and on that day, the tides are most unequal in their heights. As the Moon returns toward the equator, the parallels described by the opposite elevations approach toward each other, until the Moon comes to the equator, and then they coincide. As the Moon declines towards the opposite pole, at equal distances, each elevation describes the same parallel in the other part of the lunar day, which its opposite elevation described before.— While the Moon has north declination, the greatest tides in the northern hemisphere are when she is above the horizon, and the reverse while her declination is south. Let *N E S Q* be the Earth, *N C S* its axis, *E Q* the equator, *T* ♋ the tropic of Cancer, *t* ♑ the tropic of Capricorn, *a b* the arctic circle, *c d* the antarctic, *N* the north pole, *S* the south pole, *M* the Moon, *F* and *G* the two eminences of water, whose lowest parts are at *a* and *d* (Fig. III.) at *N* and *S* (Fig. IV.) and at *b* and *c* (Fig. V.) always 90 degrees from the highest. Now when the Moon is in her greatest north declination at *M*, the highest elevation *G* under her, is on the tropic of Cancer *T* ♋, and the opposite elevation *F* on the tropic of Capricorn, *t* ♑, and these two elevations describe the tropics by the Earth's diurnal rotation.

PLATE IX.

Fig. III. IV. V

Fig. III.

All places in the northern hemisphere *E N Q* have the highest tides when they come into the position *b* ♋ *Q*, under the Moon; and the lowest tides when the Earth's diurnal rotation carries them into the position *a T E*, on the side opposite to the Moon; the reverse happens at the same time in the southern hemisphere *E S Q*, as is evident to sight. The axis of the tides *a C d* has now its poles *a* and *d* (being always 90 degrees from the highest elevations) in the arctic and antarctic circles; and therefore it is plain, that at these circles there is but one tide

PLATE IX. Fig. IV. of flood and one of ebb, in the lunar day. For, when the point *a* revolves half round to *b*, in 12 lunar hours it has a tide of flood: but when it comes to the same point *a* again in 12 hours more, it has the lowest ebb. In seven days afterward, the Moon *M* comes to the equinoctial circle, and is over the equator *E Q*, when both elevations describe the equator; and in both hemispheres, at equal distances from the equator, the tides are equally high in both parts of the lunar day. The whole phenomena being reversed, when

Fig. V. the Moon has south declination, to what they were when her declination was north, require no farther description.

305. In the three last-mentioned figures, the earth is orthographically projected on the plane of the meridian; but in order to describe a particular phenomenon, we now project it on the plane of the ecliptic.

Fig. VI. Let *H Z O N* be the earth and sea, *F E D* the equator, *T* the tropic of Cancer, *C* the arctic circle, *P* the north pole, and the curves 1, 2, 3, &c. 24 meridians, or hour-circles, intersecting each other in the poles; *A G M* is the Moon's orbit, *S* the Sun, *M* the Moon, *Z* the water elevated under the Moon, and *N* the opposite equal elevation. As the lowest parts of the water are always 90 degrees from the highest, when the Moon is in either of the tropics (as at *M*) the elevation Z is on the tropic of Capricorn, and the opposite elevation *N* on the tropic of Cancer; the low-water circle *H C O* touches the polar circles at *C*, and the high-water circle *E T P* 6 goes over the poles at *P*, and divides every parallel of latitude into two equal segments. In this case, the tides upon every parallel are alternately higher and lower; but they return in equal times: the point *T*, for example, on the tropic of Cancer (where the depth of the tide is represented by the breadth of the dark shade) has a shallower tide of flood at *T*, than when it revolves half round from thence to 6, according to the order

When both tides are equally high in the same day, they arrive at unequal intervals of time; and vice versâ.

of the numeral figures; but it revolves as soon from 6 to *T* as it did from *T* to 6. When the Moon is in the equinoctial, the elevations *Z* and *N* are transferred to the equator at *O* and *H*, and the high and low-water circles are got into each other's former places; in which case the tides return in unequal times, but are equally high in parts of the lunar day: for a place at 1 (under *D*) revolving as formerly, goes sooner from 1 to 11 (under *F*) than from 11 to 1, because the parallel it describes is cut into unequal segments by the high-water circle *HCO*: but the points 1 and 11 being equidistant from the pole of the tides at *C*, which is directly under the pole of the Moon's orbit *MGA*, the elevations are equally high in both parts of the day.

306. And thus it appears, that as the tides are governed by the Moon, they must turn on the axis of the Moon's orbit, which is inclined $23\frac{1}{2}$ degrees to the Earth's axis at a mean state: and therefore the poles of the tides must be so many degrees from the poles of the Earth, or in opposite points of the polar circles, going round these circles in every lunar day. It is true, that according to Fig. IV. when the Moon is vertical to the Equator *ECQ*, the poles of the tides seem to fall-in with the poles of the world *N* and *S*; but when we consider that *FGH* is under the Moon's orbit, it will appear, that when the Moon is over *H*, in the tropic of Capricorn, the north pole of the tides (which can be no more than 90 degrees from under the Moon) must be at *C* in the arctic circle, not at *P*, the north pole of the Earth; and as the Moon ascends from *H* to *G* in her orbit, the north pole of the tides must shift from *c* to *a* in the arctic circle, and the south pole as much in the antarctic.

It is not to be doubted, but that the Earth's quick rotation brings the poles of the tides nearer to the

poles of the world, than they would be if the Earth were at rest, and the Moon revolved about it only once a month; for otherwise the tides would be more unequal in their heights, and times of their returns, than we find they are. But how near the Earth's rotation may bring the poles of its axis and those of the tides together, or how far the preceding tides may affect those which follow, so as to make them keep up nearly to the same heights, and times of ebbing and flowing, is a problem more fit to be solved by observation than by theory.

To know at what times we may expect the greatest and least tides.

307. Those who have opportunity to make observations, and choose to satisfy themselves whether the tides are really affected in the above manner by the different positions of the Moon, especially as to the unequal times of their returns, may take this general rule for knowing when they ought to be so affected. When the Earth's axis inclines to the Moon, the northern tides, if not retarded in their passage through shoals and channels, nor affected by the winds, ought to be greatest when the Moon is above the horizon, least when she is below it; and quite the reverse when the Earth's axis declines from her: but in both cases, at equal intervals of time. When the Earth's axis inclines sidewise to the Moon, both tides are equally high, but they happen at unequal intervals of time. In every lunation, the Earth's axis inclines once to the Moon, once from her, and twice sidewise to her, as it does to the Sun every year: because the Moon goes round the ecliptic every month, and the Sun but once in a year. In summer, the Earth's axis inclines toward the Moon when new; and therefore the day-tides in the north ought to be highest, and night tides lowest, about the change: at the full the reverse. At the quarters they ought to be equally high, but unequal in their returns; because the Earth's axis then inclines side-

wise to the Moon. In winter, the phenomena are the same at full Moon as in summer at new. In autumn, the Earth's axis inclines sidewise to the Moon when new and full; therefore the tides ought to be equally high, and unequal in their returns at these times. At the first quarter, the tides of flood should be least when the Moon is above the horizon, greatest when she is below it; and the reverse at her third quarter. In spring, the phenomena of the first quarter answer to those of the third quarter in autumn; and *vice versâ*. The nearer any time is to either of these seasons, the more the tides partake of the phenomena of these seasons; and in the middle between any two of them, the tides are at a mean state between those of both.

Why the tides rise higher in rivers than in the sea.

308. In open seas, the tides rise but to very small heights in proportion to what they do in wide-mouthed rivers, opening in the direction of the stream of tide. For, in channels growing narrower gradually, the water is accumulated by the opposition of the contracting bank. Like a gentle wind, little felt on an open plane, but strong and brisk in a street; especially if the wider end of the street be next the plane, and in the way of the wind.

The tides happen at all distances of the Moon from the meridian at different places, and why.

309. The tides are so retarded in their passage through different shoals and channels, and otherwise so variously affected by striking against capes and headlands, that to different places they happen at all distances of the Moon from the meridian; consequently at all hours of the lunar day. The tide propagated by the Moon in the *German* ocean when she is three hours past the meridian, takes 12 hours to come from thence to *London-bridge;* where it arrives by the time that a new tide is raised in the ocean. And therefore when the Moon has north declination, and we should expect the tide at *London* to be greatest when the Moon is above the horizon, we find it is least; and the contrary when she has

south declination. At several places it is high-water three hours before the Moon comes to the meridian; but that tide which the Moon pushes as it were before her, is only the tide opposite to that which was raised by her when she was nine hours past the opposite meridian.

The water never rises in lakes.

310. There are no tides in lakes, because they are generally so small, that when the Moon is vertical she attracts every part of them alike, and therefore by rendering all the water equally light, no part of it can be raised higher than another. The *Mediterranean* and *Baltic* seas have very small elevations, because the inlets by which they communicate with the ocean are so narrow, that they cannot in so short a time receive or discharge enough to raise or sink their surfaces sensibly.

The Moon raises tides in the air.

311. Air being lighter than water, and the surface of the atmosphere being nearer to the Moon than the surface of the sea, it cannot be doubted that the Moon raises much higher tides in the air than in the sea. And therefore many have wondered why the mercury does not sink in the barometer when the Moon's action on the particles of air makes them lighter as she passes over the meridian. But we must consider, that as these particles are rendered lighter, a greater number of them is accumulated, until the deficiency of gravity be made up by the height of the column; and then there is an *equilibrium*, and consequently an equal pressure upon the mercury as before; so that it cannot be affected by the aerial tides.

Why the mercury in the barometer is not affected by the aerial tides.

CHAP. XVIII.

Of Eclipses: Their Number and Periods. A large Catalogue of Ancient and Modern Eclipses.

312. EVERY planet and satellite is illuminated by the Sun, and casts a shadow toward that point of the heavens which is opposite to the Sun. This shadow is nothing but a privation of light in the space hid from the Sun by the opaque body that intercepts his rays. **A shadow what.**

313. When the Sun's light is so intercepted by the Moon, that to any place of the Earth the Sun appears partly or wholly covered, he is said to undergo an eclipse; though, properly speaking, it is only an eclipse of that part of the Earth where the Moon's shadow or * penumbra falls. When the Earth comes between the Sun and Moon, the Moon falls into the Earth's shadow; and having no light of her own, she suffers a real eclipse from the interception of the Sun's rays. When the Sun is eclipsed to us, the Moon's inhabitants on the side next the Earth (if any such inhabitants there be) see her shadow like a dark spot travelling over the Earth, about twice as fast as its equatorial parts move, and the same way as they move. When the Moon is in an eclipse, the Sun appears eclipsed to her, total to all those parts on which the Earth's shadow falls, and of as long continue as they are in the shadow. **Eclipses of the Sun and Moon, what.**

314. That the Earth is spherical (for the hills take off no more from the roundness of the Earth, than grains of dust do from the roundness of a common **A proof that the Earth and Moon are globular bodies**

* The penumbra is a faint kind of shadow all round the perfect shadow of the planet or satellite, and will be more fully explained by and by.

globe) is evident from the figure of its shadow on the Moon; which is always bounded by a circular line, although the Earth is incessantly turning its different sides to the Moon, and very seldom shews the same side to her in different eclipses, because they seldom happen at the same hours. Were the Earth shaped like a round flat plate, its shadow would only be circular when either of its sides directly faced the Moon; and more or less elliptical as the Earth happened to be turned more or less obliquely toward the Moon when she is eclipsed. The Moon's different phases prove her to be round, § 254; for as she keeps still the same side toward the Earth, if that side were flat, as it appears to be, she would never be visible from the third quarter to the first; and from the first quarter to the third, she would appear as round as when we say she is full: because at the end of her first quarter the Sun's light would come as suddenly on all her side next the Earth, as it does on a flat wall, and go off as abruptly at the end of her third quarter.

and that the Sun is much bigger than the Earth, and the Moon much less.

315. If the Earth and Sun were of equal magnitudes, the Earth's shadow would be infinitely extended, and every where of the same diameter; and the planet Mars, in either of its nodes, and opposite to the Sun, would be eclipsed in the Earth's shadow. Were the Earth bigger than the Sun, its shadow would increase in bulk the farther it extended, and would eclipse the great planets Jupiter and Saturn, with all their moons, when they were opposite to the Sun. But as Mars in opposition never falls into the Earth's shadow, although he is not then above 42 millions of miles from the Earth, it is plain that the Earth is much less than the Sun; for otherwise its shadow could not end in a point at so small a distance. If the Sun and Moon were of equal magnitude, the Moon's shadow would go on to the Earth with an equal breadth, and cover a portion of the Earth's sur-

face more than 2000 miles broad, even if it fell directly against the Earth's centre, as seen from the Moon; and much more if it fell obliquely on the Earth: but the Moon's shadow is seldom 150 miles broad at the Earth, unless when it falls very obliquely on it in total eclipses of the Sun. In annular eclipses, the Moon's real shadow ends in a point at some distance from the Earth. The Moon's small distance from the Earth, and the shortness of her shadow, prove her to be less than the Sun. And as the Earth's shadow is large enough to cover the Moon, if her diameter were three times as large as it is (which is evident from her long continuance in the shadow when she goes through its centre) it is plain that the Earth is much larger than the Moon.

The primary planets never eclipse one another. 316. Though all opaque bodies on which the Sun shines have their shadows, yet such is the bulk of the Sun, and the distances of the planets, that the primary planets can never eclipse one another. A primary can eclipse only its secondaries or be eclipsed by them; and never but when in opposition to, or conjunction with, the Sun. The Sun and Moon are so every month: whence one may imagine that these two luminaries should be eclipsed every month. But there are few eclipses in respect to the number of new and full Moons; the reason of which we shall now explain.

Why there are so few eclipses. 317. If the Moon's orbit were coincident with the plane of the ecliptic, in which the Earth always moves, and the Sun appears to move, the Moon's shadow would fall upon the Earth at every change, and eclipse the Sun to some parts of the Earth. In like manner, the Moon would go through the middle of the Earth's shadow, and be eclipsed at every full; but with this difference, that she would be totally darkened for above an hour and an half; whereas the Sun never was above four minutes totally eclipsed by the interposition of the Moon. But one half of the Moon's orbit is elevated $5\frac{1}{3}$ degrees above

The Moon's nodes.

the ecliptic, and the other half as much depressed below it: consequently the Moon's orbit intersects the ecliptic in two opposite points called *the Moon's nodes*, as has been already taken notice of, § 288. When these points are in a right line with the centre of the Sun at new or full Moon, the Sun, Moon, and Earth, are all in a right line; and if the Moon be then new, her shadow falls upon the Earth; if full, the Earth's shadow falls upon her. When the Sun and Moon are more than 17 degrees from either of the nodes at the time of conjunction, the Moon is then generally too high or too low in her orbit to cast any part of her shadow upon the Earth. And when the Sun is more than twelve degrees from either of the nodes at the time of full Moon, the Moon is generally too high or too low in her orbit to go through any part of the Earth's shadow: and in both these cases there will be no eclipse. But when the Moon is less than 17 degrees from either node at the time of conjunction, her shadow or penumbra falls more or less upon the Earth, as she is more or less within this limit.* And when she is less than 12 degrees from either node at the time of opposition, she goes through a greater or less portion of the Earth's shadow as she is more or less within this limit. Her orbit contains 360 degrees, of which 17, the limit of solar eclipses on either side of the nodes, and 12, the limit of lunar eclipses, are but small portions: and as the Sun commonly passes by the nodes but twice in a year, it is no wonder that we have so many new and full Moons without eclipses.

Limits of eclipses.

* This admits of some variation: for in apogeal eclipses, the solar limit is but 16 1-2 degrees: and in perigeal eclipses, it is 18 1-3. When the full Moon is in her apogee, she will be eclipsed if she be within 10 1-2 degrees of the node; and when she is full in her perigee, she will be eclipsed if she be within 12 $\frac{1}{36}$ degrees of the node.

To illustrate this, let *A B C D* be the *eliptic*, *R S T U* a circle lying in the same plane with the ecliptic, and *V W X Y* the *Moon's orbit*, all thrown into an oblique view, which gives them an elliptical shape to the eye. One half of the Moon's orbit, as *V W X*, is always below the ecliptic, and the other half *X Y V* above it. The points *V* and *X*, where the Moon's orbit intersects the circle *R S T U*, which lies even with the ecliptic, are the *Moon's nodes;* and a right line, as *X E V*, drawn from one to the other, through the Earth's centre, is called *the Line of the nodes*, which is carried almost parallel to itself round the Sun in a year. PLATE X. Fig 1. Lines of the nodes.

If the Moon moved round the Earth in the orbit *R S T U*, which is coincident with the plane of the ecliptic, her shadow would fall upon the Earth every time she is in conjunction with the Sun, and at every opposition she would go through the Earth's shadow. Were this the case, the Sun would be eclipsed at every change, and the Moon at every full, as already mentioned.

But although the Moon's shadow *N* must fall upon the Earth at *a*, when the Earth is at *E*, and the Moon in conjunction with the Sun, at *i*, because she is then very near one of her nodes, and at her opposition *n*, she must go through the Earth's shadow *I*, because she is then near the other node; yet, in the time that she goes round the Earth to her next change according to the order of the letters *X Y V W*, the Earth advances from *E* to *e*, according to the order of the letters *E F G H*, and the line of the nodes *V E X* being carried nearly parallel to itself, brings the point *f* of the Moon's orbit in conjunction with the Sun at that next change; and then the Moon being at *f*, is too high above the ecliptic to cast her shadow on the Earth: and as the Earth is still moving forward, the Moon at her next opposition will be at *g*, too far below the ecliptic to

PLATE X. go through any part of the Earth's shadow; for by that time the point *g* will be at a considerable distance from the Earth as seen from the Sun.

When the Earth comes to *F*, the Moon in conjunction with the Sun *Z* is not at *k*, in a plane coincident with the ecliptic, but above it at *Y* in the highest part of her orbit: and then the point *b* of her shadow *O* goes far above the Earth (as in Fig. II. which is an edge-view of Fig. I.) The Moon in her next opposition is not at *o* (Fig. I.) but at *W*, where the Earth's shadow goes far above her (as in Fig. II.) In both these cases the line of the nodes *V F X* (Fig. I.) is about 90 degrees from the Sun, and both luminaries are as far as possible from the limits of eclipses.

Fig. I. and II.

When the Earth has gone half round the ecliptic from *E* to *G*, the line of the nodes *V G X* is nearly, if not exactly, directed towards the Sun at *Z*; and then the new Moon *l* casts her shadow *P* on the Earth *G*; and the full Moon *p* goes through the Earth's shadow *L*; which brings on eclipses again, as when the Earth was at *E*.

When the Earth comes to *H*, the new Moon falls not at *m* in a plane coincident with the ecliptic *C D*, but at *W* in her orbit below it: and then her shadow *Q* (see Fig. II.) goes far below the Earth. At the next full she is not at *q* (Fig. I.) but at *Y* in her orbit $5\frac{1}{3}$ degrees above *q*, and at her greatest height above the ecliptic *C D*; being then as far as possible, at any opposition, from the Earth's shadow *M* (as in Fig. II.)

So, when the Earth is at *E* and *G*, the Moon is about her nodes at new and full; and in her greatest *north* and *south declination* (or latitude as it is generally called) from the ecliptic at her quarters: but when the Earth is at *F* or *H*, the Moon is in her greatest *north* and *south declination* from the ecliptic at new and full, and in the *nodes* about her quarters.

318. The point *X* where the Moon's orbit crosses the ecliptic is called the *ascending node*, because the Moon ascends from it above the ecliptic: and the opposite point of intersection *V* is called *the descending node*, because the Moon descends from it below the ecliptic. When the Moon is at *Y* in the highest point of her orbit, she is in her greatest *north latitude*: and when she is at *W* in the lowest point of her orbit, she is in her greatest *south latitude*.

PLATE X.

The Moon's ascending and descending nodes.

Her north and south latitude.

319. If the line of the nodes, like the Earth's axis, were carried parallel to itself round the Sun, there would be just half a year between the conjunctions of the Sun and nodes. But the nodes shift backward, or contrary to the Earth's annual motion, $19\frac{1}{3}$ degrees every year; and therefore the same node comes round to the Sun 19 days sooner every year than on the year before. Consequently, from the time that the ascending node *X* (when the Earth is at *E*) passes by the Sun, as seen from the Earth, it is only 173 days (not half a year) till the descending node *V* passes by him. Therefore, in whatever time of the year we have eclipses of the luminaries about either node, we may be sure that in 173 days afterward, we shall have eclipses about the other node. And when at any time of the year the line of the nodes is in the situation *V G X*, at the same time next year it will be in the situation *r G s*; the ascending node having gone backward, that is, contrary to the order of signs, from *X* to *s*, and the descending node from *V* to *r*; each $19\frac{1}{3}$ degrees. At this rate the nodes shift through all the signs and degrees of the ecliptic in 18 years and 225 days; in which time there would always be a regular period of eclipses, if any complete number of lunations were finished without a fraction. But this never happens; for if both the Sun and Moon should start from a line of conjunction with either of the nodes in any point of the ecliptic, the Sun would

The nodes have a retrograde motion,

Fig. I.

which brings on the eclipses sooner every year than they would be if the nodes had not such a motion.

perform 18 annual revolutions and 222 degrees over and above, and the Moon 230 lunations and 85 degrees of the 231st, by the time the node came round to the same point of the ecliptic again; so that the Sun would then be 138 degrees from the node, and the Moon 85 degrees from the Sun.

A period of eclipses. 320. But, in 223 mean lunations, after the Sun, Moon, and nodes, have been once in a line of conjunction, they return so nearly to the same state again, as that the same node, which was in conjunction with the Sun and Moon at the beginning of the first of these lunations, will be within 28′ 12″ of a degree of a line of conjunction with the Sun and Moon again, when the last of these lunations is completed. And therefore, in that time, there will be a regular period of eclipses, or return of the same eclipse for many ages.—In this period, (which was first discovered by the *Chaldeans)* there are 18 *Julian* years 11 days 7 hours 43 minutes 20 seconds, when the last day of *February* in leap-years is four times included: but when it is five times included, the period consists of only 18 years 10 days 7 hours 43 minutes 20 seconds. Consequently, if to the mean time of any eclipse, either of the Sun or Moon, you add 18 *Julian* years 11 days 7 hours 43 minutes 20 seconds, when the last day of *February* in leap-years comes in four times, or a day less when it comes in five times, you will have the mean time of the return of the same eclipse.

But the falling-back of the line of conjunctions or oppositions of the Sun and Moon 28′ 12″ with respect to the line of the nodes in every period, will wear it out in process of time; and after that, it will not return again in less than 12492 years.—These eclipses of the Sun, which happen about the ascending node, and begin to come in at the north pole of the Earth, will go a little southerly at each return, till they go quite off the Earth at the south

pole; and those which happen about the descending node, and begin to come in at the south pole of the Earth, will go a little northerly at each return, till at last they quite leave the Earth at the north pole.

To exemplify this matter, we shall first consider the Sun's eclipse, *March* 21st old stile (*April* 1st new stile) A. D. 1764, according to its mean revolutions, without equating the times, or the Sun's distance from the node; and then according to its true equated times.

This eclipse fell in the open space at each return, quite clear of the Earth, from the creation till A. D. 1295, *June* 13th old stile, at 12 h. 52 m. 59 sec. *post meridiem*, when the Moon's shadow first touched the Earth at the north pole; the Sun being then 17° 48′ 27″ from the ascending node.—In each period since that time, the Sun has come 28′ 12″ nearer and nearer the same node, and the Moon's shadow has therefore gone more and more southerly.—In the year 1962, *July* 18th old stile, at 10 h. 36 m. 21 sec. *p. m.* when the same eclipse will have returned 38 times, the Sun will be only 24′ 45″ from the ascending node, and the centre of the Moon's shadow will fall a little northward of the Earth's centre.—At the end of the next following period, A. D. 1980, *July* 28th old stile, at 18 h. 19 m. 41 sec. *p. m.* the Sun will have receded back 3′ 27″ from the ascending node, and the Moon will have a very small degree of southern latitude, which will cause the centre of her shadow to pass a very small matter south of the Earth's centre.—After which, in every following period, the Sun will be 28′ 12″ farther back from the ascending node than in the period last before; and the Moon's shadow will go still farther and farther southward, until *September* 12th old stile, at 23 h. 46 m. 22 sec. *p. m.* A. D. 2665; when the eclipse will have completed its 77th periodical return, and will go quite off the Earth at the south pole (the Sun being then

17° 55′ 22″ back from the node); and it cannot come in from the north pole, so as to begin the same course over again, in less than 12492 years afterward.—And such will be the case of every other eclipse of the Sun: for, as there is about 18 degrees on each side of the node within which there is a possibility of eclipses, their whole revolution goes through 36 degrees about that node, which, taken from 360 degrees, leaves remaining 324 degrees for the eclipses to travel *in expansum*. And as these 36 degrees are not gone through in less than 77 periods, which take up 1388 years, the remaining 324 degrees cannot be so gone through in less than 12492 years. For as 36 is to 1388, so is 324 to 12492.

321. In order to shew both the mean and true times of the returns of this eclipse, through all its periods, together with the mean anomalies of the Sun and Moon at each return, and the mean and true distances of the Sun from the Moon's ascending node, and the Moon's true latitude at the true time of each new Moon, I have calculated the following tables for the sake of those who may choose to project this eclipse at any of its returns, according to the rules laid down in the XVth chapter; and have by that means taken by much the greatest part of the trouble off their hands.—All the times are according to the old stile, for the sake of a regularity which, with respect to the nominal days of the months, does not take place in the new: but by adding the days difference of stile; they are reduced to the times which agree with the new stile.

According to the mean (or supposed) equable motions of the Sun, Moon, and nodes, the Moon's shadow in this eclipse would have first touched the Earth at the north pole, on the 13th of *June*, A. D. 1295, at 12 h. 52 m. 59 sec. past noon on the meridian of *London*; and would quite leave the Earth at the

south pole, on the 12th of *September*, A. D. 2665, at 23 h. 46 m. 22 sec. past noon, at the completion of its 77th period; as shewn by the first and second tables.

But, on account of the true or unequable motions of the Sun, Moon, and nodes, the first coming in of this eclipse, at the north pole of the Earth, was on the 24th of *June*, A. D. 1313, at 3 h. 57 m. 3 sec. past noon; and it will finally leave the earth at the south pole, on the 31st of *July*, A. D. 2593, at 10 h. 25 m. 31 sec. past noon, at the completion of its 72d period; as shewn by the third and fourth tables.—So that the true motions do not only alter the true times from the mean, but they also cut off five periods from those of the mean returns of this eclipse.

TABLE I. *The mean time of New Moon, with the mean Anomalies of the Sun and Moon, and the Sun's mean Distance from the Moon's Ascending Node, at the mean time of each periodical Return of the Sun's Eclipse,* March 21st, 1764, *from its first coming upon the Earth since the creation, till it falls right against the Earth's centre, according to the Old Style.*

Periodical Returns.	Years of Christ.	Mean time of New Moon.					Sun's mean Anomaly.				Moon's mean Anomaly.				Sun's mean dist from the Node			
		Month.	D.	H.	M.	S.	s.	o.	'	"	s.	o.	'	"	s.	o.	'	"
0	1277	June	2	5	9	39	11	17	57	41	1	26	31	42	0	18	16	40
1	1295	June	13	12	52	59	11	28	27	38	1	23	40	19	0	17	48	27
2	1313	June	23	20	36	19	0	8	57	35	1	20	48	56	0	17	20	15
3	1331	July	5	4	19	30	0	19	27	32	1	17	57	35	0	16	52	2
4	1349	July	15	12	2	59	0	29	57	29	1	15	6	10	0	16	23	50
5	1367	July	26	19	46	19	1	10	27	26	1	12	14	47	0	15	55	37
6	1385	Aug.	6	3	29	39	1	20	57	23	1	9	23	24	0	15	27	25
7	1403	Aug.	17	11	12	59	2	1	27	20	1	6	32	1	0	14	59	12
8	1421	Aug.	27	18	56	19	2	11	57	17	1	3	40	38	0	14	31	0
9	1439	Sept.	8	2	39	39	2	22	27	14	1	0	49	15	0	14	2	47
10	1457	Sept.	18	10	2	59	3	2	57	11	0	27	57	52	0	13	34	35
11	1475	Sept.	29	18	6	19	3	13	27	8	0	25	6	29	0	13	6	22
12	1493	Oct.	10	1	49	39	3	23	57	5	0	22	15	6	0	12	38	10
13	1511	Oct.	21	9	32	59	4	4	27	2	0	19	23	43	0	12	9	57
14	1529	Oct.	31	17	16	19	4	14	56	59	0	16	32	20	0	11	41	45
15	1547	Nov.	12	0	59	40	4	25	26	56	0	13	40	57	0	11	13	32
16	1565	Nov.	22	8	43	0	5	5	56	53	0	10	49	34	0	10	45	20
17	1583	Dec.	3	16	26	20	5	16	26	50	0	7	58	9	0	10	17	7
18	1601	Dec.	14	0	9	40	5	26	56	47	0	5	6	48	0	9	48	55
19	1619	Dec.	25	7	53	0	6	7	26	44	0	2	15	25	0	9	20	42
20	1638	Jan.	4	15	36	20	6	17	56	41	11	29	24	2	0	8	52	30
21	1656	Jan.	15	23	19	40	6	28	26	38	11	26	32	39	0	8	24	17
22	1674	Jan.	26	7	3	0	7	8	56	35	11	23	41	14	0	7	56	5
23	1692	Feb.	6	14	46	20	7	19	26	32	11	20	49	53	0	7	27	52
24	1710	Feb.	16	22	29	40	7	29	56	29	11	17	58	30	0	6	59	40
25	1728	Feb.	28	6	13	0	8	10	26	26	11	15	7	7	0	6	31	27
26	1746	Mar.	10	13	56	20	8	20	56	23	11	12	15	44	0	6	3	15
27	1764	Mar.	20	21	39	40	9	1	26	20	11	9	24	21	0	5	35	2
28	1782	Apr.	1	5	23	0	9	11	56	17	11	6	32	58	0	5	6	50
29	1800	Apr.	11	13	6	20	9	22	26	14	11	3	41	35	0	4	38	37
30	1818	Apr.	22	20	49	40	10	2	56	11	11	0	50	12	0	4	10	25
31	1836	May	3	4	33	0	10	13	26	8	10	27	58	49	0	3	42	12
32	1854	May	14	12	16	20	10	23	56	5	10	25	7	26	0	3	14	0
33	1872	May	24	19	59	40	11	4	26	2	10	22	16	3	0	2	45	47
34	1890	June	5	3	43	0	11	14	55	59	10	19	24	40	0	2	17	35
35	1908	June	15	11	26	20	11	25	25	56	10	16	33	17	0	1	49	22
36	1926	June	26	19	9	40	0	5	55	53	10	13	41	54	0	1	21	10
37	1944	July	7	2	53	0	0	16	25	50	10	10	50	31	0	0	52	57
38	1962	July	18	10	36	21	0	26	55	47	10	7	59	8	0	0	24	45

TABLE II. *The mean time of New Moon, with the mean Anomalies of the Sun and Moon, and the Sun's mean Distance from the Moon's Ascending Node, at the mean Time of each periodical Return of the Sun's Eclipse,* March 21*st*, 1764, *from the mean Time of its falling right against the Earth's Centre, till it finally leaves the Earth according to the Julian, or Old Style.*

Periodic Returns.	Years of Christ	Mean time of New Moon.					Sun's mean Anomaly.				Moon's mean Anomaly.				Sun's mean dist. from the Node.			
		Month.	D.	H.	M.	S.	s.	o.	'	"	s.	o.	'	"	s.	o.	'	"
39	1980	July	28	18	19	41	1	7	25	44	10	5	7	45	11	29	56	33
40	1998	Aug.	9	2	3	1	1	17	55	41	10	2	16	22	11	29	28	20
41	2016	Aug.	19	9	46	21	1	28	25	38	9	29	24	59	11	29	0	8
42	2034	Aug.	30	17	29	41	2	8	55	36	9	26	33	36	11	28	31	55
43	2052	Sept.	10	1	13	1	2	19	25	33	9	23	42	13	11	28	3	43
44	2070	Sept.	21	8	56	21	2	29	55	32	9	20	50	50	11	27	35	30
45	2088	Oct.	1	16	39	41	3	10	25	27	9	17	59	27	11	27	7	18
46	2106	Oct.	13	0	23	1	3	20	55	24	9	15	8	4	11	26	39	5
47	2124	Oct.	23	8	6	21	4	1	25	21	9	12	16	41	11	26	10	53
48	2142	Nov.	3	15	49	41	4	11	55	18	9	9	25	18	11	25	42	40
49	2160	Nov.	13	23	31	1	4	22	25	15	9	6	33	56	11	25	14	28
50	2178	Nov.	25	7	16	21	5	2	55	12	9	3	42	33	11	24	46	15
51	2196	Dec.	5	14	59	41	5	13	25	9	9	0	51	10	11	24	18	3
52	2214	Dec.	16	22	43	1	5	23	55	7	8	27	59	47	11	23	49	50
53	2232	Dec.	27	6	26	21	6	4	25	4	8	25	8	24	11	23	21	38
54	2251	Jan.	7	14	9	41	6	14	55	1	8	22	17	1	11	22	53	25
55	2269	Jan.	17	21	53	1	6	25	24	58	8	19	25	38	11	22	15	13
56	2287	Jan.	29	5	36	21	7	5	54	55	8	16	31	15	11	21	57	0
57	2305	Feb.	8	13	19	41	7	16	24	52	8	13	42	52	11	21	28	48
58	2323	Feb.	19	21	3	1	7	26	54	49	8	10	51	29	11	21	0	35
59	2341	Mar.	2	4	46	21	8	7	24	46	8	8	0	6	11	20	32	23
60	2359	Mar.	13	12	29	42	8	17	54	43	8	5	8	43	11	20	4	10
61	2377	Mar.	23	20	13	2	8	28	24	40	8	2	17	20	11	19	35	58
62	2395	Apr.	4	3	56	22	9	8	54	37	7	29	25	27	11	19	7	45
63	2413	Apr.	14	11	39	42	9	19	24	34	7	26	34	34	11	18	39	33
64	2431	Apr.	25	19	23	2	9	29	54	31	7	23	43	11	11	18	11	20
65	2449	May	6	3	0	22	10	10	24	28	7	20	51	48	11	17	43	8
66	2467	May	17	10	49	42	10	20	54	25	7	18	0	25	11	17	14	54
67	2485	May	27	18	33	2	11	1	24	22	7	15	9	2	11	16	46	43
68	2503	June	8	2	16	22	11	11	54	19	7	12	17	39	11	16	18	31
69	2521	June	18	9	59	42	11	22	24	17	7	9	26	16	11	15	50	18
70	2539	June	29	17	43	2	0	2	54	14	7	6	34	53	11	15	22	6
71	2557	July	10	1	26	22	0	13	24	11	7	3	44	30	11	14	53	54
72	2575	July	21	9	9	42	0	23	54	8	7	0	52	7	11	14	25	41
73	2593	July	31	16	53	2	1	4	24	5	6	28	0	44	11	13	57	28
74	2611	Aug.	12	0	36	22	1	14	54	2	6	25	9	21	11	13	29	16
75	2629	Aug.	22	8	19	42	1	25	23	59	6	22	17	58	11	13	1	3
76	2647	Sept.	2	16	3	2	2	5	53	56	6	19	26	35	11	12	32	51
77	2665	Sept.	12	23	46	22	2	16	23	53	6	16	35	12	11	12	4	38

TABLE III. *The true Time of New Moon, with the Sun's true Distance from the Moon's Ascending Node, and the Moon's true Latitude, at the true Time of each periodical Return of the Sun's Eclipse,* March 21st, *Old Style,* A. D. 1764, *from the Time of its first coming upon the Earth since the Creation till it falls right against the Earth's Centre.*

Periodical Returns	Years of Christ	True Time of New Moon					Sun's true Dist. from the Node.				Moon's true Latitude North.			
		Month.	D.	H.	M.	S.	s.	°	′	″	°.	′	″	Nor.
0	1295	June	13	12	54	32	0	18	40	54	1	33	45	N. A.
1	1312	June	24	3	57	3	0	17	20	22	1	29	84	N. A.
2	1231	July	5	10	42	8	0	16	29	35	1	25	20	N. A.
3	1349	July	15	17	14	15	0	15	34	18	1	20	45	N. A.
4	1367	July	26	23	49	24	0	14	46	8	1	16	39	N. A.
5	1385	Aug	6	6	41	17	0	13	59	43	2	13	43	N. A.
6	1403	Aug.	17	13	32	19	0	13	16	44	1	9	3	N. A
7	1421	Aug	27	20	30	17	0	12	37	4	1	5	42	N. A.
8	1439	Sept.	8	3	51	46	0	12	1	54	1	2	41	N. A
9	1457	Sept.	18	10	23	11	0	11	30	27	0	58	53	N. A.
10	1475	Sept.	29	17	57	7	0	11	3	56	0	57	43	N. A.
11	1493	Oct.	16	1	44	3	0	10	41	55	0	55	49	N. A.
12	1511	Oct.	21	9	29	53	0	10	25	11	0	54	28	N. A.
13	1529	Oct.	31	17	9	18	0	10	11	27	0	53	12	N. A.
14	1547	Nov.	12	0	51	25	0	10	1	10	0	52	19	N. A.
15	1565	Nov.	22	8	54	56	0	9	52	49	0	51	46	N. A.
16	1583	Dec.	3	16	48	17	0	9	48	4	0	51	11	N. A.
17	1601	Dec.	4	0	51	5	0	9	43	42	0	50	49	N. A.
18	1619	Dec.	25	8	54	59	0	9	40	23	0	50	31	N. A.
19	1638	Jan.	4	16	56	1	0	9	34	57	0	50	3	N. A.
20	1656	Jan	16	0	54	41	0	9	29	24	0	49	57	N. A.
21	1674	Jan	26	8	48	24	0	9	19	44	0	48	44	N. A.
22	1692	Feb.	6	16	36	28	0	9	8	56	0	47	49	N. A.
23	1710	Feb.	17	0	8	37	0	8	54	26	0	46	14	N A.
24	1728	Feb.	28	7	43	46	0	8	34	53	0	44	12	N. A.
25	1746	Mar.	10	15	14	37	0	8	10	38	0	42	46	N. A.
26	1764	Mar.	20	22	30	26	0	7	42	14	0	40	18	N A.
27	1782	Apr.	1	5	37	4	0	7	9	27	0	37	28	N. A.
28	1800	Apr.	11	12	36	38	0	6	35	30	0	34	31	N. A
29	1818	Apr.	22	19	27	34	0	5	51	48	0	30	[illegible]	N. A.
30	1836	May	3	2	12	7	0	5	5	5	0	26	16	N. A.
31	1854	May	14	8	50	40	0	4	19	45	0	22	42	N. A
32	1872	May	24	15	38	15	0	3	26	3	0	18	1	N. A.
33	1890	June	4	22	8	[illegible]	0	2	35	5	0	13	[illegible]	N A.
34	1908	June	15	4	26	23	0	1	41	45	0	8	54	N. A.
35	1926	June	26	11	13	5	0	0	47	38	0	4	10	N. A.

On account of the differences between the mean and true new Moons, and between the Sun's mean and true distances from the node, the Moon's shadow falls even with the Earth's centre two periods sooner in this table than in the first

TABLE IV. *The true Time of New Moon, with the Sun's true Distance from the Moon's Ascending Node, and the Moon's true Latitude at each periodical Return of the Sun's Eclipse,* March 21*st, Old Style,* A. D. 1764, *from its falling right against the Earth's centre, till it finally leaves the Earth.*

Periodical Returns.	Years of Christ.	True Time of New Moon					Sun's true Dist. from the Node.				Moon's true Latitude South.			
		Month.	D.	H.	M.	S.	s.	°	′	″	°	′	″	South.
36	1944	July	6	17	50	35	11	29	55	28	0	0	24	S. A.
37	1962	July	18	0	31	38	11	29	2	35	0	5	2	S. A.
38	1980	July	28	7	18	53	11	28	11	32	0	9	29	S. A.
39	1998	Aug.	8	14	12	22	11	27	26	41	0	13	25	S. A.
40	2016	Aug.	18	21	14	53	11	26	42	16	0	17	18	S. A.
41	2034	Aug.	30	4	25	45	11	26	2	0	0	20	48	S. A.
42	2052	Sept.	9	11	45	17	11	25	26	46	0	23	53	S. A.
43	2070	Sept.	20	19	17	26	11	24	55	4	0	26	39	S. A.
44	2088	Oct.	1	2	57	8	11	24	27	43	0	28	58	S. A.
45	2106	Oct.	12	10	47	39	11	24	4	38	0	31	2	S. A.
46	2124	Oct.	22	18	37	40	11	23	48	28	0	32	26	S. A.
47	2142	Nov.	3	2	56	19	11	23	35	11	0	33	53	S. A.
48	2160	Nov.	13	11	11	20	11	23	22	22	0	34	42	S. A.
49	2178	Nov.	24	19	36	14	11	23	18	57	0	35	0	S. A.
50	2196	Dec.	5	4	4	9	11	23	14	40	0	35	22	S. A.
51	2214	Dec.	16	12	35	48	11	23	10	43	0	35	43	S. A.
52	2232	Dec.	26	20	29	9	11	23	6	47	0	36	1	S. A.
53	2251	Jan.	7	5	42	9	11	23	4	27	0	36	16	S. A.
54	2269	Jan.	17	14	14	8	11	23	0	41	0	36	35	S. A.
55	2287	Jan.	28	22	43	34	11	22	53	58	0	37	10	S. A.
56	2305	Feb.	8	7	8	30	11	22	44	44	0	37	59	S. A.
57	2323	Feb.	19	15	7	10	11	22	31	1	0	39	8	S. A.
58	2341	Mar.	2	0	6	5	11	22	17	46	0	40	28	S. A.
59	2359	Mar.	13	7	59	17	11	21	55	29	0	42	9	S. A.
60	2377	Mar.	23	15	51	59	11	21	39	40	0	43	41	S. A.
61	2395	Apr.	3	23	45	7	11	21	0	53	0	46	58	S. A.
62	2413	Apr.	14	7	32	40	11	20	26	22	0	49	48	S. A.
63	2431	Apr.	25	15	12	57	11	19	47	34	0	53	17	S. A.
64	2449	May	5	22	45	14	11	19	6	22	0	56	50	S. A.
65	2467	May	17	6	17	30	11	18	21	16	1	0	40	S. A.
66	2485	May	27	13	46	29	11	17	34	20	1	4	42	S. A.
67	2503	June	7	21	10	31	11	16	43	17	1	9	3	S. A.
68	2521	June	18	4	24	42	11	15	51	48	1	13	25	S. A.
69	2539	June	29	11	58	46	11	15	1	12	1	17	43	S. A.
70	2557	July	9	19	24	7	11	14	9	13	1	22	6	S. A.
71	3575	July	21	2	52	34	11	13	19	22	1	26	16	S. A.
72	2593	July	31	10	25	31	11	12	13	43	1	31	44	S. A.
0	2611	Aug.	11	17	58	39	11	11	45	13	1	36	13	S. A.

By the true motions of the Sun, Moon, and nodes, this eclipse goes off the Earth four periods soonr than it would have done by mean equable motions.

From Mr G. SMITH's dissertation on eclipses, printed at *London*, by E. CAVE, in the year 1748.

"To illustrate this a little farther, we shall examine some of the most remarkable circumstances of the returns of the eclipse, which happened *July* 14, 1748, about noon. This eclipse, after traversing the voids of space from the creation, at last began to enter the *Terra Australis Incognita*, about 88 years after the Conquest, which was the last of King STEPHEN's reign; every *Chaldean** period it has crept more northerly, but was still invisible in *Britain* before the year 1622; when on the 30th of *April* it began to touch the south parts of *England* about 2 in the afternoon its central appearance rising in the *American* South Seas, and traversing *Peru* and the *Amazons'* country, through the *Atlantic* ocean into *Africa*, and setting in the *Ethiopian* continent, not far from the beginning of the Red Sea.

"Its next visible period was after three *Chaldean* revolutions, in 1676, on the first of *June*, rising central in the *Atlantic* ocean, passing us about 9 in the morning, with four † digits eclipsed on the under limb; and setting in the gulph of *Cochin-china*, in the *East-Indies*.

"It being now near the solstice, this eclipse was visible the very next return in 1694, in the evening; and in two periods more, which was in 1730, on the 4th of *July*, was seen above half eclipsed just after sun-rise, and observed both at *Wittemburg* in *Germany*, and *Pekin* in *China*, soon after which it went off.

"Eighteen years more afforded us the eclipse which fell on the 14th of *July*, 1748.

"The next visible return will happen on *July* 25, 1766, in the evening, about four digits eclipsed;

* The above period of 18 years, 11 days, 7 hours, 43 minutes, 20 seconds, was found out by the *Chaldeans*, and by them called *Saros*.

† A digit is the twelfth part of the diameter of the Sun, or Moon.

" and after two periods more, on *August* 16th, " 1802, early in the morning, about five digits, the " centre coming from the north frozen continent, by " the capes of *Norway*, through *Tartary*, *China* " and *Japan*, to the *Ladrone* islands, where it goes " off.

" Again, in 1820, *August* 26, betwixt one and " two, there will be another great eclipse at *London*, " about 10 digits; but happening so near the equi- " nox, the centre will leave every part of *Britain* to " the west, and enter *Germany* at *Embden*, passing " by *Venice*, *Naples*, *Grand Cairo*, and set in the " gulf of *Bassora* near that city.

" It will be no more visible till 1874, when five " digits will be obscured (the centre being now " about to leave the Earth) on *September* 28. In " 1892, the Sun will go down eclipsed at *London*, " and again in 1928 the passage of the centre will be " in the expansion, though there will be two digits " eclipsed at *London*, *October* the 31st of that year; " and about the year 2090 the whole penumbra will " be worn off; whence no more returns of this eclipse " can happen till after a revolution of ten thousand " years.

" From these remarks on the entire revolution of " this eclipse, we may gather that a thousand years " more or less, (for there are some irregularities that " may protract or lengthen this period 100 years), " complete the whole terrestrial phenomena of any " single eclipse: and since 20 periods of 54 years " each, and about 33 days, comprehend the entire " extent of their revolution, it is evident that the " times of the returns will pass through a circuit of " one year and ten months, every *Chaldean* period " being ten or eleven days later, and of the equa- " ble appearances about 32 or 33 days. Thus, " though this eclipse happens about the middle of " *July*, no other subsequent eclipse of this period " will return to the middle of the same month again;

" but wear, constantly each period 10 or 11 days " forward; and at last appear in winter, but then it " begins to cease from affecting us.

" Another conclusion from this revolution may " be drawn, that there will seldom be any more than " two great eclipses of the Sun in the interval of " this period, and these follow sometimes next return, " and often at greater distances. That of 1715 re- " turned again in 1733 very great; but this present " eclipse will not be great till the arrival of 1820, " which is a revolution of four *Chaldean* periods; " so that the irregularities of their circuits must " undergo new computations to assign them ex- " actly.

" Nor do all eclipses come in at the south pole: " *that* depends altogether on the position of the lu- " nar nodes, which will bring in as many from the " *expansum* one way as the other: and such eclips- " es will wear more southerly by degrees; contrary " to what happens in the present case.

" The eclipse, for example, of 1736, in *Septem- " ber*, had its centre in the *expansum*, and set about " the middle of its obscurity in *Britain;* it will wear " in at the north pole, and in the year 2600, or " thereabout, go off in the *expansum* on the south " side of the Earth.

" The eclipses therefore which happened about " the creation are little more than half way yet of " their ethereal circuit; and will be 4000 years be- " fore they enter the Earth any more. This grand " revolution seems to have been entirely unknown " to the ancients.

Why our present tables agree not with ancient observation.

322. " It is particularly to be noted, that eclipses " which have happened many centuries ago, will not " be found by our present tables to agree exactly with " ancient observations, by reason of the great anoma- " lies in the lunar motions; which appears an incon- " testable demonstration of the non-eternity of the " universe. For it seems confirmed by undeni-

" able proofs, that the Moon now finishes her period " in less time than formerly, and will continue by " the centripetal law to approach nearer and nearer " the Earth, and to go sooner and sooner round it: " nor will the centrifugal power be sufficient to com- " pensate the different gravitations of such an as- " semblage of bodies as constitute the solar system, " which would come to ruin of itself, without some " new regulation and adjustment of their original " motions*.

323. " We are credibly informed from the testi- " mony of the ancients, that there was a total eclipse THALES'S eclipse.

* There are two ancient eclipses of the Moon, recorded by *Ptolemy* from *Hipparchus*, which afford an undeniable proof of the Moon's acceleration. The first of these was observed at *Babylon*, *December* the 22d, in the year before CHRIST 383: when the Moon began to be eclipsed about half an hour before the Sun rose, and the eclipse was not over before the Moon set: but by most of our astronomical tables the Moon was set at *Babylon* half an hour before the eclipse began; in which case, there could have been no possibility of observing it. The second eclipse was observed at *Alexandria*, *September* the 22d, the year before CHRIST 201; where the Moon rose so much eclipsed, that the eclipse must have begun about half an hour before she rose; whereas, by most of our tables, the beginning of this eclipse was not till about ten minutes after the Moon rose at *Alexandria*. Had these eclipses begun and ended while the Sun was below the horizon, we might have imagined, that as the ancients had no certain way of measuring time, they might have been so far mistaken in the hours, that we could not have laid any stress on the accounts given by them. But, as in the first eclipse the Moon was set, and consequently the Sun was risen, before it was over; and in the second eclipse the Sun was set and the Moon not risen, till some time after it began; these are such circumstances as the observers could not possibly be mistaken in. Mr. *Struyk*, in the following catalogue, notwithstanding the express words of *Ptolemy*, puts down these two eclipses as observed at *Athens*; where they might have been seen as above, without any acceleration of the Moon's motion: *Athens* being 20 degrees west of *Babylon*, and 7 degrees west of *Alexandria*.

" of the Sun predicted by THALES to happen in the " fourth year of the 48th * *Olympiad*, either at *Sardis* or *Miletus* in *Asia*, where THALES then resided. That year corresponds to the 585th year " before Christ; when accordingly there happened " a very signal eclipse of the Sun, on the 28th of " *May*, answering to the present 10th of that month †, " central through *North America*, the south parts of

* Each *Olympiad* began at the time of full Moon next after the summer-solstice, and lasted four years, which were of unequal lengths, because the time of full Moon differs 11 days every year: so that they might sometimes begin on the next day after the solstice, and at other times not till four weeks after it. The first *Olympiad* began in the year of the Julian period 3938, which was 776 years before the first year of CHRIST, or 775 before the year of his birth; and the last *Olympiad*, which was the 293d, began *A. D.* 293. At the expiration of each *Olympiad*, the *Olympic Games* were celebrated in the *Elean* fields, near the river *Alpheus* in the *Peloponnesus* (now *Morea*) in honour of JUPITER OLYMPUS. See STRAUCHIUS's *Breviarium Chronologicum*, p. 247—251.

† The reader may probably find it difficult to understand why Mr. SMITH should reckon this eclipse to have been in the 4th year of the 48th *Olympiad*, as it was only in the end of the third year: and also why the 28th of *May*, in the 585th year before CHRIST, should answer to the present 10th of that month. But we hope the following explanation will remove these difficulties.

The month of *May* (when the Sun was eclipsed) in the 585th year before the first year of CHRIST, which was a leap-year, fell in the latter end of the third year of the 48th *Olympiad*; and the fourth year of that *Olympiad* began at the summer-solstice following: but perhaps Mr. SMITH begins the year of the *Olympiad* from *January*, in order to make them correspond more readily with *Julian* years; and so reckons the month of *May*, when the eclipse happened, to be in the fourth year of that *Olympiad*.

The place or longitude of the Sun at that time was ♉ 29° 43′ 17″, to which same place the Sun returned (after 2300 years,) *viz. A. D.* 1716, on *May* 9d 5h 6m after noon: so that, with respect to the Sun's place, the 9th of *May*, 1716, answers to the 28th of *May* in the 585th year before the first year of CHRIST; that is, the Sun had the same longitude on both those days.

" *France*, *Italy*, &c. as far as *Athens*, or the isles
" in the *Ægean* Sea; which is the farthest that even
" the *Caroline* tables carry it; and consequently
" make it invisible to any part of *Asia*, in the total
" character; though I have good reasons to believe
" that it extended to *Babylon*, and went down central over that city. We are not however to imagine, that it was set before it passed *Sardis* and the *Asiatic* towns, where the predictor lived; because an invisible eclipse could have been of no service to demonstrate his ability in astronomical sciences to his countrymen, as it could give no proof of its utility.

4. " For a further illustration, Thucydides relates, that a solar eclipse happened on a summer's day in the afternoon, in the first year of the " *Peloponnesian* war, so great that the stars appeared. Rhodius was victor in the *Olympic* games " the fourth year of the said war, being also the " fourth of the 87th *Olympiad*, on the 428th year " before Christ. So that the eclipse must have " happened in the 431st year before Christ: and " by computation it appears, that on the 3d of *August* there was a signal eclipse which would have " passed over *Athens*, central about 6 in the evening, but which our present tables bring no farther " than the ancient *Syrtes* on the *African* coast, above " 400 miles from *Athens*; which suffering in that " case but 9 digits, could by no means exhibit the " remarkable darkness recited by this historian; the " centre therefore seems to have passed *Athens* about " 6 in the evening, and probably might go down " about *Jerusalem*, or near it, contrary to the construction of the present tables. I have only obviated these things by way of caution to the present astronomers, in re-computing ancient eclipses; and refer them to examine the eclipse of *Nicias*, so fatal to the *Athenian* fleet*; that which

Thucydides's eclipse.

* Before Christ 413, *August* 27.

"overthrew the *Macedonian* army*, &c." So far Mr. SMITH.

The number of eclipses. 325. In any year, the number of eclipses of both luminaries cannot be less than two, nor more than seven; the most usual number is four, and it is very rare to have more than six. For the Sun passes by both the nodes but once a year, unless he passes by one of them in the beginning of the year; and when he does, he will pass by the same node again a little before the year be finished; because as these points move $19\frac{1}{3}$ degrees backward every year, the Sun will come to either of them 173 days after the other, § 319. And when either node is within 17 degrees of the Sun at the time of new Moon, the Sun will be eclipsed. At the subsequent opposition, the Moon will be eclipsed in the other node; and come round to the next conjunction again ere the former node be 17 degrees past the Sun, and will therefore eclipse him again. When three eclipses fall about either node, the like number generally falls about the opposite; as the Sun comes to it in 173 days afterward; and six lunations contain but four days more. Thus there may be two eclipses of the Sun and one of the Moon about each of her nodes. But when the Moon changes in either of the nodes, she cannot be near enough the other node at the next full to be eclipsed; and in six lunar months afterward she will change near the other node: in these cases there can be but two eclipses in a year, and they will be both of the Sun.

326. A longer period than the above mentioned, § 320, for comparing and examining eclipses which happened at long intervals of time, is 557 years 21 days 18 hours 30 minutes 11 seconds, in which time there are 6890 mean lunations: and the Sun and node meet again so nearly as to be but 11 seconds distant; but then it is not the same eclipse that returns, as in the shorter period above-mentioned.

* Before CHRIST 168, *June* 21.

327. We shall subjoin a catalogue of eclipses recorded in history, from 721 years before CHRIST to *A. D.* 1485; of computed eclipses from 1485 to 1700: and of all the eclipses visible in *Europe* from 1700 to 1800. From the beginning of the catalogue to *A. D.* 1485, the eclipses are taken from STRUYK's *Introduction to Universal Geography*, as that indefatigable author has, with much labour, collected them from *Ptolemy*, *Thucydides*, *Plutarch*, *Calvisius*, *Xenophon*, *Diodorus Siculus*, *Justin*, *Polybius*, *Titus Livius*, *Cicero*, *Lucanus*, *Theophanes*, *Dion*, *Cassius*, and many others. From 1485 to 1700 the eclipses are taken from *Ricciolus's Almagest:* and from 1700 to 1800 from *L'Art de vérifier les Dates*. Those from *Struyk* have all the places mentioned where they were observed: Those from the *French* authors, *viz.* the religious *Benedictines* of the congregation of *St. Maur*, are fitted to the meridian of *Paris:* And concerning those from *Ricciolus*, that author gives the following account:

An account of the following catalogue of eclipses.

"Because it is of great use for fixing the cycles or revolutions of eclipses, to have at hand, without the trouble of calculation, a list of successive eclipses for many years, computed by authors of *ephemerides*, although from tables not perfect in all respects, I shall, for the benefit of astronomers, give a summary collection of such. The authors I extract from are: an anonymous one who published *ephemerides* from 1484 to 1506 inclusive: *Jacobus Pflaumen* and *Jo. Stæflerinus*, to the meridian of *Ulm*, from 1507 to 1534: *Lucas Gauricus*, to the latitude of 45 degrees, from 1534 to 1551: *Peter Appian*, to the meridian of *Leysing*, from 1538 to 1578: *Jo. Stæflerus*, to the meridian of *Tubing*, from 1543 to 1554: *Petrus Pitatus*, to the meridian of *Venice*, from 1554 to 1556: *Georgius Joachimus Rheticus*, for the year 1551: *Nicholas Simus*, to the meridian of *Bologna*, from 1552 to 1568: *Michael Mæstlin*, to the meridian of *Tubing*, from 1557 to 1590: *Jo.*

Stadius, to the meridian of *Antwerp*, from 1554 to 1574: *Jo. Antoninus Maginus*, to the meridian of *Venice*, from 1581 to 1630: *David Origan* to the meridian of *Franckfort* on the *Oder*, from 1595 to 1664: *Andrew Argol*, to the meridian of *Rome*, from 1630 to 1700: *Franciscus Montebrunus*, to the meridian of *Bologna*, from 1461 to 1660: Among which, *Stadius*, *Mæstlin*, and *Maginus*, used the *Prutenic* tables; *Origan* the *Prutenic* and *Tychonic; Montebrunus* the *Lansbergian*, as likewise those of *Durat*. Almost all the rest the *Alphonsine*.

"But that the places may readily be known for which these eclipses were computed, and from what tables, consult the following list, in which the years *inclusive* are also set down:

From	To	
1485	1506	The place and author unknown.
1507	1553	*Ulm* in *Suabia*, from the *Alphonsine*.
1554	1576	*Antwerp*, from the *Prutenic*.
1577	1585	*Tubing*, from the *Prutenic*.
1586	1594	*Venice*, from the *Prutenic*.
1595	1600	*Franckfort* on the *Oder*, from the *Prutenic*.
1601	1640	*Franckfort* on the *Oder*, from the *Tychonic*
1641	1660	*Bologna*, from the *Lansbergian*.
1661	1700	*Rome*, from the *Tychonic*."

So far Ricciolus.

N. B. The eclipses marked with an asterisk are not in Ricciolus's catalogue, but are supplied from *L'Art de vérifier les Dates*.

From the beginning of the catalogue to *A.D.* 1700, the time is reckoned from the noon of the day mentioned to the noon of the following day: but from 1700 to 1800 the time is set down according to our common way of reckoning. Those marked *Pekin* and *Canton* are eclipses from the *Chinese* chronology according to Struyk; and throughout the table this mark ☉ signifies *Sun*, and ☽ *Moon*.

STRUYK's CATALOGUE OF ECLIPSES.

Bef. Chr.	Eclipses of the Sun and Moon seen at		M. and D.		Middle H.	M	Digits eclipsed.	
721	Babylon	☽	March	19	10	34	Total	
720	Babylon	☽	March	8	11	56	1	5
720	Babylon	☽	Sept.	1	10	18	5	4
621	Babylon	☽	Apr.	21	18	22	2	36
523	Babylon	☽	July	16	12	47	7	24
502	Babylon	☽	Nov.	19	12	21	1	52
491	Babylon	☽	April	25	12	12	1	44
431	Athens	☉	Aug.	3	6	35	11	0
425	Athens	☽	Oct.	9	6	45	Total	
424	Athens	☉	March	20	20	17	9	0
413	Athens	☽	Aug.	27	10	15	Total	
406	Athens	☽	Apr.	15	8	50	Total	
404	Athens	☉	Sept.	2	21	12	8	40
403	Pekin	☉	Aug.	28	5	53	10	40
394	Gnide	☉	Aug.	13	22	17	11	0
383	Athens	☽	Dec.	22	19	6	2	1
382	Athens	☽	June	18	8	54	6	15
382	Athens	☽	Dec.	12	10	21	Total	
364	Thebes	☉	July	12	23	51	6	10
357	Syracuse	☉	Feb.	28	22	—	3	33
357	Zant	☽	Aug.	29	7	29	4	21
340	Zant	☉	Sept.	14	18	—	9	0
331	Arbela	☽	Sept.	20	20	9	Total	
310	Sicily Island	☉	Aug.	14	20	5	10	22
219	Mysia	☽	March	19	14	5	Total	
218	Pergamos	☽	Sept.	1	rising		Total	
217	Sardinia	☉	Feb.	11	1	57	9	6
203	Frusini	☉	May	6	2	52	5	40
202	Cumis	☉	Oct.	18	22	24	1	0
201	Athens	☽	Sept.	22	7	14	8	58
200	Athens	☽	March	19	13	9	Total	
200	Athens	☽	Sept.	11	14	48	Total	
198	Rome	☉	Aug.	9	—	—	—	
190	Rome	☉	March	13	18	—	11	0
188	Rome	☉	July	16	20	38	10	48
174	Athens	☽	April	30	14	33	7	1
168	Macedonia	☽	June	21	8	2	Total	
141	Rhodes	☽	Jan.	27	10	8	3	26
104	Rome	☉	July	18	22	0	11	52
63	Rome	☽	Oct.	27	6	22	Total	
60	Gibraltar	☉	March	16	setting		Central	
54	Canton	☉	May	9	3	47	Total	
51	Rome	☉	March	7	2	12	9	0
48	Rome	☽	Jan.	18	10	0	Total	
45	Rome	☽	Nov.	6	4	—	Total	
36	Rome	☉	May	19	3	5	6	47

STRUYK's CATALOGUE OF ECLIPSES.

Bef. Chr.	Eclipses of the Sun and Moon seen at		M. and D.		Middle H.	M	Digits eclipsed.	
31	Rome	☉	Aug.	20	setting		Gr. Ecl.	
29	Canton	☉	Jan.	5	4	2	11	0
28	Pekin	☉	June	18	23	48	Total	
26	Canton	☉	Oct.	23	4	16	11	15
24	Pekin	☉	April	7	4	11	2	0
16	Pekin	☉	Nov.	1	5	13	2	8
2	Canton	☉	Feb.	1	20	8	11	42
Aft. Chr.								
1	Pekin	☉	June	10	1	10	11	43
5	Rome	☉	March	28	4	13	4	45
14	Pannonia	☽	Sept.	26	17	15	Total	
27	Canton	☉	July	22	8	56	Total	
30	Canton	☉	Nov.	13	19	20	10	30
40	Pekin	☉	April	30	5	50	7	34
45	Rome	☉	July	31	22	1	5	17
46	Pekin	☉	July	21	22	25	2	10
46	Rome	☽	Dec.	31	9	52	Total	
49	Pekin	☉	May	20	7	16	10	8
53	Canton	☉	March	8	20	42	11	6
55	Pekin	☉	July	12	21	50	6	40
56	Canton	☉	Dec.	25	0	28	9	20
59	Rome	☉	April	30	3	8	10	38
60	Canton	☉	Oct.	13	3	31	10	30
65	Canton	☉	Dec.	15	21	50	10	23
69	Rome	☽	Oct.	18	10	43	10	49
70	Canton	☉	Sept.	22	21	13	8	26
71	Rome	☽	March	4	8	32	6	0
95	Ephesus	☉	May	21	——		1	0
125	Alexandria	☽	April	5	9	16	1	44
133	Alexandria	☽	May	6	11	44	Total	
134	Alexandria	☽	Oct.	20	11	5	10	19
136	Alexandria	☽	March	5	15	50	5	17
237	Bologna	☉	April	12	——		Total	
238	Rome	☉	April	1	20	20	8	45
290	Carthage	☉	May	15	3	20	11	20
304	Rome	☽	Aug.	31	9	30	Total	
316	Constantinople	☉	Dec.	30	19	53	2	18
334	Toledo	☉	July	17	at noon		Central	
348	Constantinople	☉	Oct.	8	19	24	8	0
360	Ispahan	☉	Aug.	27	18	0	Central	
364	Alexandria	☽	Nov.	25	15	24	Total	
401	Rome	☽	June	11	——		Total	
401	Rome	☽	Dec.	6	12	1.	Total	
402	Rome	☽	June	1	8	4	10	2

STRUYK's CATALOGUE OF ECLIPSES.

Aft. Chr.	Eclipses of the Sun and Moon seen at		M. and D.		Middle H.	M	Digits eclipsed.	
402	Rome	☉	Nov.	10	20	33	10	30
447	Compostello	☉	Dec.	23	0	46	1	—
451	Compostello	☽	April	1	16	34	19	52
451	Compostello	☽	Sept.	26	6	30	0	2
458	Chaves	☉	May	27	23	16	18	53
462	Compostello	☽	March	1	13	2	11	11
464	Chaves	☉	July	19	19	1	10	15
484	Constantinople	☉	Jan.	13	19	53	10	0
486	Constantinople	☉	May	19	1	10	5	15
497	Constantinople	☉	April	18	6	5	17	57
512	Constantinople	☉	June	28	23	8	1	50
538	England	☉	Feb.	14	19	—	8	23
540	London	☉	June	19	20	15	8	—
577	Tours	☽	Dec.	10	17	28	6	46
581	Paris	☽	April	4	13	33	6	42
582	Paris	☽	Sept.	17	12	41	Total	
590	Paris	☽	Oct.	18	6	30	9	25
592	Constantinople	☉	March	18	22	6	10	0
603	Paris	☉	Aug.	12	3	3	11	20
622	Constantinople	☽	Feb.	1	11	28	Total	
644	Paris	☉	Nov.	5	0	30	9	53
680	Paris	☽	June	17	12	30	Total	
683	Paris	☽	April	16	11	30	Total	
693	Constantinople	☉	Oct.	4	23	54	11	54
716	Constantinople	☽	Jan.	13	7	—	Total	
718	Constantinople	☉	June	3	1	15	Total	
733	England	☉	Aug.	13	20	—	11	1
734	England	☽	Jan.	23	14	—	Total	
752	England	☽	July	30	13	—	Total	
753	England	☉	June	8	22	—	10	35
753	England	☽	Jan.	23	13	—	Total	
760	England	☉	Aug.	15	4	—	8	15
760	London	☽	Aug.	30	5	50	10	40
764	England	☉	June	4	at noon		7	15
770	London	☽	Feb.	14	7	12	Total	
774	Rome	☽	Nov.	22	14	37	11	58
784	London	☽	Nov.	1	14	2	Total	
787	Constantinople	☉	Sept.	14	20	43	9	47
796	Constantinople	☽	March	27	16	22	Total	
800	Rome	☽	Jan.	15	9	0	10	17
807	Angoulesme	☉	Feb.	10	21	24	9	42
807	Paris	☽	Feb.	25	13	43	Total	
807	Paris	☽	Aug.	21	10	20	Total	
809	Paris	☉	July	15	21	33	8	8
809	Paris	☽	Dec.	25	8	—	Total	
810	Paris	☽	June	20	8	—	Total	

STRUYK's CATALOGUE OF ECLIPSES.

Aft. Chr.	Eclipses of the Sun and Moon seen at		M. and D.		Middle H.	M.	Digits eclipsed.	
810	Paris	☉	Nov.	30	0	12	Total	
810	Paris	☽	Dec.	14	8	—	Total	
812	Constantinople	☉	May	14	2	13	9	—
813	Cappadocia	☉	May	3	17	5	10	35
817	Paris	☽	Feb.	5	5	42	Total	
818	Paris	☉	July	6	18	—	6	35
820	Paris	☽	Nov.	23	6	26	Total	
824	Paris	☽	March	18	7	55	Total	
828	Paris	☽	June	30	15	—	Total	
828	Paris	☽	Dec.	24	13	45	Total	
831	Paris	☽	April	30	6	19	11	8
831	Paris	☉	May	15	23	—	4	24
831	Paris	☽	Oct.	24	11	16	Total	
832	Paris	☽	April	18	9	0	Total	
840	Paris	☉	May	4	23	22	9	20
841	Paris	☉	Oct.	17	18	56	5	24
842	Paris	☽	March	29	14	36	Total	
843	Paris	☽	March	19	7	1	Total	
861	Paris	☽	March	29	15	7	Total	
878	Paris	☽	Oct.	14	16	—	Total	
878	Paris	☉	Oct.	29	1	—	11	14
883	Arracta	☽	July	23	7	44	11	—
889	Constantinople	☉	April	3	17	52	9	23
891	Constantinople	☉	Aug.	7	23	48	10	30
901	Arracta	☽	Aug.	2	15	7	Total	
904	London	☽	May	31	11	47	Total	
904	London	☽	Nov.	25	9	0	Total	
912	London	☽	Jan.	6	15	12	Total	
926	Paris	☽	March	31	15	17	Total	
934	Paris	☉	April	16	4	30	11	36
939	Paris	☉	July	18	19	45	10	7
955	Paris	☽	Sept.	4	11	18	Total	
961	Rhemes	☉	May	16	20	13	9	18
970	Constantinople	☉	May	7	18	36	11	22
976	London	☽	July	13	15	7	Total	
985	Messina	☉	July	20	3	52	4	10
989	Constantinople	☉	May	28	6	54	8	40
990	Fulda	☽	April	12	10	22	9	5
990	Fulda	☽	Oct.	6	15	4	1	10
990	Constantinople	☉	Oct.	21	0	45	10	5
995	Augsburgh	☽	July	14	11	27	Total	
1009	Ferrara	☽	Oct.	6	11	[illegible]	Total	
1010	Messina	☽	March	18	5	41	9	12
1016	Nimeguen	☉	Nov.	16	16	39	Total	
1017	Nimeguen	☉	Oct.	22	2	8	6	—
1020	Cologne	☽	Sept.	4	11	33	Total	

STRUYK's CATALOGUE OF ECLIPSES.

Aft. Chr.	Eclipses of the Sun and Moon seen at		M. and D.	Middle H.	Middle M.	Digits eclipsed.
1023	London	☉	Jan. 23	23	29	11 —
1030	Rome	☽	Feb. 20	11	43	Total
1031	Paris	☽	Feb. 9	11	51	Total
1033	Paris	☽	Dec. 8	11	11	9 17
1034	Milan	☽	June 4	9	8	Total
1037	Paris	☉	Apr. 17	20	45	10 45
1039	Auxerre	☉	Aug. 21	23	40	11 5
1042	Rome	☽	Jan. 8	16	39	Total
1044	Auxerre	☽	Nov. 7	16	12	10 1
1044	Cluny	☉	Nov. 21	22	12	11 —
1056	Nuremburg	☽	April 2	12	9	Total
1063	Rome	☽	Nov. 8	12	16	Total
1074	Augsburgh	☽	Oct. 7	10	13	Total
1080	Constantinople	☽	Nov. 29	11	12	9 36
1082	London	☽	May 14	10	32	10 2
1086	Constantinople	☉	Feb. 16	4	7	Total
1089	Naples	☽	June 25	6	6	Total
1093	Augsburgh	☉	Sept. 22	22	35	10 12
1096	Gembluors	☽	Feb. 10	16	4	Total
1096	Augsburgh	☽	Aug. 6	8	21	Total
1098	Augsburgh	☉	Dec. 25	1	25	0 13
1099	Naples	☽	Nov. 30	4	58	Total
1103	Rome	☽	Sept. 17	10	18	Total
1106	Erfurd	☽	July 17	11	28	11 54
1107	Naples	☽	Jan. 10	13	16	Total
1109	Erfurd	☉	May 31	1	30	10 20
1110	London	☽	May 5	10	51	Total
1113	Jerusalem	☉	March 18	19	0	9 12
1114	London	☽	Aug. 17	15	5	Total
1117	Triers	☽	June 15	13	26	Total
1117	Triers	☽	Dec. 10	12	51	Total
1110	Naples	☽	Nov. 20	15	46	4 11
1121	Triers	☽	Sept. 27	16	47	Total
1122	Prague	☽	March 24	11	20	3 49
1124	Erfurd	☽	Feb. 1	6	43	8 39
1124	London	☉	Aug. 10	23	29	9 58
1132	Erfurd	☽	March 3	8	14	Total
1133	Prague	☽	Feb. 20	16	41	3 23
1135	London	☽	Dec. 22	20	11	Total
1142	Rome	☽	Feb. 11	14	17	8 30
1143	Rome	☽	Feb. 1	6	36	Total
1147	Auranches	☉	Oct. 25	22	38	7 20
1149	Bary	☽	March 25	13	54	5 29
1151	Eimbeck	☽	Aug. 28	12	4	4 29
1153	Augsburgh	☉	Jan. 26	0	42	11 —
1154	Paris	☽	June 36	16	1	Total

STRUYK's CATALOGUE OF ECLIPSES.

Aft. Chr.	Eclipses of the Sun and Moon seen at		M. and D.		Middle H.	M.	Digits eclipsed	
1154	Paris	☽	Dec.	21	8	30	4	22
1155	Auranches	☽	June	16	8	45	0	53
1160	Rome	☽	Aug.	18	7	53	6	49
1161	Rome	☽	Aug.	7	8	11	Total	
116[illegible]	Erfurd	☽	Feb.	1	6	40	5	56
1162	Erfurd	☽	July	27	21	30	4	11
1163	Mont Cassini	☉	July	3	7	40	2	0
1164	Milan	☽	June	6	10	0	Total	
1168	London	☽	Sept.	18	14	0	Total	
1172	Cologne	☽	Jan.	11	13	31	Total	
1176	Auranches	☽	April	25	7	2	8	6
1176	Auranches	☽	Oct.	19	11	20	8	53
1178	Cologne	☽	March	15	setting		7	52
1178	Auranches	☽	Aug.	29	13	52	5	31
1178	Cologne	☉	Sept.	12	—	—	10	51
1179	Cologne	☽	Aug.	18	14	28	Total	
1180	Auranches	☉	Jan.	28	4	14	10	34
1181	Auranches	☉	July	13	3	15	3	48
1181	Auranches	☽	Dec.	22	8	58	4	40
1185	Rhemes	☉	May	1	1	53	9	0
1186	Cologne	☽	April	5	6	—	Total	
1186	Frankfort	☉	April	20	7	19	4	0
1187	Paris	☽	March	25	16	17	8	42
1187	England	☉	Sept.	3	21	54	8	6
1189	England	☽	Feb.	2	10	—	9	—
1191	England	☉	June	23	0	20	11	32
1192	France	☽	Nov.	20	14	—	6	—
1193	France	☽	Nov	10	5	27	Total	
1194	London	☉	April	22	2	15	6	49
1200	London	☽	Jan.	2	17	2	4	35
1201	London	☽	June	17	15	4	Total	
1204	England	☽	April	15	12	39	Total	
1204	Saltzburg	☽	Oct.	10	6	32	Total	
1207	Rhemes	☉	Feb.	27	10	50	10	20
1208	Rhemes	☽	Feb.	2	5	10	Total	
1211	Vienna	☽	Nov.	21	13	57	Total	
1215	Cologne	☽	March	16	15	35	Total	
1216	Acre	☉	Feb.	18	21	15	11	36
1216	Acre	☽	March	5	9	28	7	4
1218	Damietta	☽	July	9	9	46	11	31
122[illegible]	Rome	☽	Oct.	23	14	28	Total	
122[illegible]	Colmar	☽	April	16	8	13	11	0
1228	Naples	☉	Dec.	27	9	55	9	19
1230	Naples	☉	May	13	17	—	Total	
1230	London	☽	Nov.	21	13	21	9	34
1[illegible]	Rhemes	☉	Oct.	15	4	29	4	25

STRUYK's CATALOGUE OF ECLIPSES.

Aft. Chr.	Eclipses of the Sun and Moon seen at		M. and D.		Middle H.	M.	Digits eclipsed.	
1245	Rhemes	☉	July	27	17	47	6	—
1248	London	☽	June	7	8	49	Total	
1255	London	☽	July	20	9	47	Total	
1255	Constantinople	☉	Dec.	30	2	52	Annul.	
1258	Augsburgh	☽	May	18	11	17	Total	
1261	Vienna	☉	March	31	22	40	9	8
1262	Vienna	☽	March	7	5	50	Total	
1262	Vienna	☽	Aug.	30	14	39	Total	
1263	Vienna	☽	Feb.	24	6	52	6	29
1263	Augsburgh	☉	Aug.	5	3	24	11	17
1263	Vienna	☽	Aug.	20	7	35	9	7
1265	Vienna	☽	Dec.	23	16	25	Total	
1267	Constantinople	☉	May	24	23	11	11	40
1270	Vienna	☉	March	22	18	47	10	40
1272	Vienna	☽	Aug.	10	7	27	8	53
1274	Vienna	☽	Jan.	23	10	39	9	25
1275	Lauben	☽	Dec.	4	6	20	4	29
1276	Vienna	☽	Nov.	22	15	—	Total	
1277	Vienna	☽	May	18	—	—	Total	
1279	Franckfort	☉	April	12	6	55	10	6
1280	London	☽	March	17	12	12	Total	
1284	Reggio	☽	Dec.	23	16	11	9	13
1290	Wittemburg	☉	Sept.	5	19	37	10	30
1291	London	☽	Feb.	14	10	2	Total	
1302	Constantinople	☽	Jan.	14	10	25	Total	
1307	Ferrara	☉	April	2	22	18	0	54
1309	London	☽	Feb.	24	17	44	Total	
1309	Lucca	☽	Aug.	21	10	32	Total	
1310	Wittemburg	☉	Jan.	31	2	2	10	10
1310	Torcella	☽	Feb.	14	4	8	10	20
1310	Torcella	☽	Aug.	10	15	33	7	16
1312	Wittemburg	☉	July	4	19	49	3	23
1312	Plaisance	☽	Dec.	14	7	19	Total	
1313	Torcello	☽	Dec.	3	8	58	9	34
1316	Modena	☽	Oct.	1	14	55	Total	
1321	Wittemburg	☉	June	25	18	1	11	17
1323	Florence	☽	May	20	15	24	Total	
1324	Florence	☽	May	9	6	3	Total	
1324	Wittemburg	☉	April	23	6	35	8	8
1327	Constantinople	☽	Aug.	31	18	26	Total	
1328	Constantinople	☽	Feb.	25	13	47	11	—
1330	Florence	☽	June	30	15	10	7	34
1330	Constantinople	☉	July	16	4	5	10	43
1330	Prague	☽	Dec.	25	15	49	Total	
1331	Prague	☉	Nov.	29	20	26	7	41
1331	Prague	☽	Dec.	14	18	—	11	—

STRUYK's CATALOGUE OF ECLIPSES.

Aft. Chr.	Eclipses of the Sun and Moon seen at		M. and D.	Middle H.	M.	Digits eclipsed.
1333	Wittemburg	☉	May 14	3	—	10 18
1334	Cesena	☽	April 19	10	33	Total
1341	Constantinople	☽	Nov. 23	12	23	Total
1341	Constantinople	☉	Dec. 8	22	15	6 30
1342	Constantinople	☽	May 20	14	27	Total
1344	Alexandria	☉	Oct. 6	18	40	8 55
1349	Wittemburg	☽	June 30	12	20	Total
1354	Wittemburg	☉	Sept. 16	20	45	8 43
1356	Florence	☽	Feb. 16	11	43	Total
1361	Constantinople	☉	May 4	22	15	8 54
1367	Sienna	☽	Jan. 16	8	27	Total
1389	Eugibio	☽	Nov. 3	17	5	Total
1396	Augsburgh	☉	Jan. 11	0	[illegible]	6 22
1396	Augsburgh	☽	June 21	11	10	Total
1399	Forli	☉	Oct. 29	0	45	9 —
1406	Constantinople	☽	June 1	13	—	10 31
1406	Constantinople	☉	June 15	[illegible]	1	11 38
1408	Forli	☉	Oct. 18	21	47	9 32
1409	Constantinople	☉	April 15	3	1	10 46
1410	Vienna	☽	March 20	13	13	Total
1415	Wittemburg	☉	June 6	6	43	Total
1419	Franckfort	☉	March 25	22	5	1 45
1421	Forli	☽	Feb. 17	8	2	Total
1422	Forli	☽	Feb. 6	8	26	11 7
1424	Wittemburg	☉	June 26	3	57	11 20
1431	Forli	☉	Feb. 12	2	4	1 39
1433	Wittemburg	☉	June 17	5	—	Total
1438	Wittemburg	☉	Sept. 18	20	59	8 7
1442	Rome	☽	Dec. 17	[illegible]	59	Total
1448	Tubing	☉	Aug. 28	22	23	8 53
1450	Constantinople	☽	July 24	7	19	Total
1457	Vienna	☽	Sept. 3	11	17	Total
1460	Austria	☽	July [illegible]	7	31	5 23
1460	Austria	☉	July 17	17	32	11 19
1460	Vienna	☽	Dec. 27	13	30	Total
1461	Vienna	☽	June 22	11	50	Total
1461	Rome	☽	Dec. 17	—	—	Total
1462	Viterbo	☽	June 11	15	—	7 38
1462	Viterbo	☉	Nov. 21	0	10	2 6
1464	Padua	☽	April 21	12	43	Total
1465	Rome	☉	Sept. 20	5	15	8 46
1465	Rome	☽	Oct. 4	5	12	Total
1469	Rome	☽	Jan. 27	7	9	Total
1485	Nurimburg	☉	March 16	3	55	11 —

All the following ECLIPSES, are taken from RICCIOLUS, except those marked with an Asterisk, which are from *L'Art de vérifier les Dates.*

Aft. Chr.		M. & D.		Middle H.	M	Digits eclipsed		Aft. Chr.		M. & D.		Middle H.	M.	Digits eclipsed	
1486	☽	Feb.	18	5	41	Total		1508	☉	May	29	6	—	*	
1486	☉	March	5	17	43	9	0	1508	☽	June	12	17	40	Total	
1487	☽	Feb.	7	15	49	Total		1509	☽	June	2	11	11	7	0
1487	☉	July	20	2	6	7	0	1509	☉	Nov.	11	22	—	*	
1486	☽	Jan.	28	6	—	*		1510	☽	Oct.	16	19	—	*	
1488	☉	July	8	17	30	4	0	1511	☽	Oct.	6	11	50	Total	
1489	☽	Dec.	7	17	41	Total		1512	☽	Sept.	25	3	56	Total	
1490	☉	May	19	Noon		*		1513	☉	March	7	0	30	6	0
1490	☽	June	2	10	6	Total		1513	☉	July	30	1	—	*	
1490	☽	Nov.	26	18	25	Total		1515	☽	Jan.	29	15	18	Total	
1491	☉	March	8	2	19	9		1516	☽	Jan.	19	6	0	Total	
1491	☽	Nov.	15	18	—	*		1516	☽	July	13	11	37	Total	
1492	☉	April	26	7	—	*		1516	☉	Dec.	23	3	47	3	0
1492	☉	Oct.	20	23	—	*		1517	☉	June	18	16	—	*	
1493	☽	April	21	14	0	Total		1517	☽	Nov.	27	19	—	*	
1493	☉	Oct.	10	2	40	8	0	1518	☽	May	24	11	19	9	11
1494	☉	March	7	4	12	4	0	1518	☉	June	7	17	56	11	0
1494	☽	March	21	14	38	Total		1519	☉	May	28	1	—	*	
1494	☽	Sept.	14	19	45	Total		1519	☉	Oct.	23	4	33	6	0
1495	☽	March	10	16	—	*		1519	☽	Nov.	6	6	24	Total	
1495	☉	Aug.	19	17	—	*		1520	☽	May	2	7	—	*	
1496	☽	Jan.	29	14	—	*		1520	☉	Oct.	11	5	22	3	
1497	☽	Jan.	18	6	38	Total		1520	☽	Oct.	25	19	—	*	
1497	☉	July	29	3	2	3	0	1520	☽	March	21	17	—	*	
1499	☽	June	22	17	—	*		1521	☉	April	6	19	—	*	
1499	☉	Aug.	23	18	—	*		1521	☉	Sept.	30	3	—	*	
1499	☽	Nov.	17	10	—	*		1522	☽	Sept.	5	12	17	Total	
1500	☉	March	27	In the		Night		1523	☽	March	1	8	26	Total	
1500	☽	April	11		At	Noon		1523	☽	Aug.	25	15	24	Total	
1501	☽	Oct.	5	14	2	10	0	1524	☉	Feb.	4	1	—	*	
1502	☽	May	2	17	49	Total		1524	☽	Aug.	16	16	—	*	
1502	☉	Sept.	30	19	45	10	0	1525	☉	Jan.	23	4	—	*	
1503	☽	Oct.	15	12	20	2	0	1525	☽	July	4	10	10	Total	
1503	☽	March	12	9	—	*		1525	☽	Dec.	29	10	45	Total	
1503	☉	Sept.	19	22	—	*		1526	☽	Dec.	[illegible]	10	30	Total	
1504	☽	Feb.	29	13	26	Total		1527	☉	Jan.	2	3	—	*	
1504	☉	March	16	3	—	*		1527	☽	Dec.	7	10	—	*	
1505	☽	Aug.	14	8	18	Total		1528	☉	May	17	20	—	*	
1506	☽	Feb.	7	15	—	*		1529	☽	Oct.	16	20	23	11	55
1507	☉	July	20	3	11	2	0	1530	☉	March	28	18	23	8	4
1506	☽	Aug.	3	10	—	*		1530	☽	Oct.	6	12	11	Total	
1507	☉	Jan.	12	19	—	*		1531	☽	April	1	7	—	*	
1508	☉	Jan.	2	4	—	*		1532	☉	Aug.	30	0	40	3	

RICCIOLUS's CATALOGUE OF ECLIPSES.

Aft. Chr.		M. & D.		Middle H.	M.	Digits eclipsed	Aft. Chr.		M. & D.		Middle H.	M.	Digits eclipsed
1533	☽	Aug.	4	11	50	Total	1556	☉	Nov.	1	18	0	9 41
1533	☉	Aug.	19	17	—	*	1556	☽	Nov.	16	12	44	6 55
1534	☉	Jan.	14	1	42	5 45	1557	☉	Oct.	20	20	—	*
1534	☽	Jan.	29	14	25	Total	1558	☽	April	2	11	0	9 50
1535	☉	June	30	Noon		*	1558	☉	April	18	1	—	*
1535	☽	July	14	8	—	*	1559	☽	April	16	4	50	Total
1535	☉	Dec.	24	2	—	*	1560	☽	March	11	15	40	4 13
1536	☉	June	18	2	2	8 0	1560	☉	Aug.	21	1	0	6 22
1536	☽	Nov.	27	6	24	10 15	1560	☽	Sept.	3	7	—	*
1537	☽	May	24	8	3	Total	1561	☉	Feb.	13	29	—	*
1537	☉	June	7	8	—	*	1562	☉	Feb.	3	5	—	*
1537	☽	Nov.	16	14	56	Total	1562	☽	July	15	15	50	Total
1538	☽	May	13	14	24	2 0	1563	☉	Jan.	22	19	—	*
1538	☽	Nov.	6	5	31	3 37	1563	☉	June	20	4	50	8 38
1539	☉	April	8	4	33	9 0	1563	☽	July	5	8	4	11 34
1540	☉	April	6	17	15	Total	1565	☉	March	7	12	53	———
1541	☽	March	11	16	34	Total	1565	☽	May	14	16	—	*
1541	☉	Aug.	21	0	56	3	1565	☽	Nov.	7	12	46	11 46
1542	☽	March	1	8	46	1 38	1566	☽	Oct.	28	5	38	Total
1542	☉	Aug.	10	17	—	*	1567	☉	April	8	23	4	6 34
1543	☽	July	15	16	—	*	1567	☽	Oct.	17	13	43	2 40
1544	☽	Jan.	9	18	13	Total	1568	☉	March	28	5	—	*
1544	☉	Jan.	23	21	16	11 17	1569	☽	March	2	15	18	Total
1544	☽	July	4	8	31	Total	1570	☽	Feb.	20	5	46	Total
1544	☽	Dec.	28	18	27	Total	1570	☽	Aug.	15	9	17	Total
1545	☉	June	8	20	48	3′ 45	1571	☉	Jan.	25	4	—	*
1545	☽	Dec.	17	18	—	*	1572	☉	Jan.	14	19	—	*
1546	☉	May	30	5	—	*	1572	☽	June	25	9	0	5 26
1546	☉	Nov.	22	23	—	*	1573	☉	June	28	18	—	*
1547	☽	May	4	0	27	8 0	1573	☉	Nov.	24	4	—	*
1547	☽	Oct.	28	4	56	11 34	1573	☉	Dec.	8	6	51	Total
1547	☉	Nov.	12	2	9	9 30	1574	☽	Nov.	13	3	50	5 21
1548	☉	April	8	3	—	*	1575	☉	May	19	8	—	6
1548	☽	April	22	11	24	Total	1575	☉	Nov.	2	5	—	*
1549	☽	April	11	15	19	2 0	1576	☽	Oct.	7	9	45	———
1549	☽	Oct.	6	6	—	*	1577	☽	April	2	8	33	Total
1550	☉	March	10	20	—	*	1577	☽	Sept.	26	13	4	Total
1551	☽	Feb.	20	8	21	Total	1578	☽	Sept.	15	13	4	2 20
1551	☉	Aug.	31	2	0	1 52	1579	☉	Feb.	15	5	41	8 36
1553	☉	Jan.	12	22	54	1 22	1579	☉	Aug.	20	19	0	*
1553	☉	July	10	7	—	*	1580	☽	Jan.	31	10	7	Total
1553	☽	July	24	16	0	0 31	1581	☽	Jan.	19	9	22	Total
1554	☉	June	29	6	—	*	1581	☽	July	15	17	51	Total
1554	☽	Dec.	8	13	7	10 12	1582	☽	Jan.	8	10	29	0 53
1555	☽	June	4	15	0	Total	1582	☉	June	9	17	5	7 5
1555	☉	Nov.	13	19	—	*	1583	☽	Nov.	28	21	51	Total

RICCIOLUS's CATALOGUE OF ECLIPSES.

Aft. Chr.		M. & D.		Middle H.	M.	Digits eclipsed		Aft. Chr.		M. & D.		Middle H.	M.	Digits eclipsed	
1584	☉	May	9	18	20	3	36	1601	☽	June	15	6	18	4	52
1584	☽	Nov.	17	14	15	Total		1601	☉	June	29	China		4	29
1585	☉	April	2	7	53	11	7	1601	☽	Dec.	9	7	6	10	53
1585	☽	May	13	5	9	6	54	1601	☉	Dec.	24	2	46	9	52
1586	☽	Sept.	27	8	—	*		1602	☉	May	21	Greenl		2	41
1586	☉	Oct.	12	Noon		*		1602	☽	June	4	7	18	Total	
1587	☽	Sept.	10	9	28	10	2	1602	☉	June	19	N. Gra.		5	43
1588	☉	Feb.	26	1	23	1	3	1602	☉	Nov.	13	Magel.		3	—
1588	☽	March	12	14	14	Total		1602	☽	Nov.	28	10	2	Total	
1588	☽	Sept.	4	17	30	Total		1603	☉	May	10	China		11	21
1589	☉	Aug.	10	18	—	*		1603	☽	May	24	11	41	7	59
1589	☽	Aug.	25	8	1	3	45	1603	☉	Nov.	3	Rom. I.		11	17
1590	☉	Feb.	4	5	—	*		1903	☽	Nov.	18	7	31	3	26
1590	☽	July	16	17	4	3	54	1604	☉	April	20	Arabia		9	32
1590	☉	July	30	19	57	10	27	1604	☉	Oct.	22	Peru		6	49
1591	☽	Jan.	9	6	21	9	40	1605	☽	April	3	9	19	11	49
1591	☽	July	6	5	8	Total		1605	☉	April	18	Madag.		5	31
1591	☉	July	20	4	2	1	0	1605	☽	Sept.	27	4	27	9	26
1591	☽	Dec.	29	16	11	Total		1605	☉	Oct.	12	2	32	9	24
1592	☽	June	24	10	13	8	58	1606	☉	March	8	Mexico		6	0
1592	☽	Dec.	18	7	24	5	54	1606	☽	March	24	11	17	Total	
1593	☉	May	30	2	30	2	38	1606	☉	Sept.	2	Magel.		6	40
1594	☉	May	19	14	58	10	23	1606	☉	Sept.	2	Magel		6	40
1594	☽	Oct.	28	19	15	9	40	1606	☽	Sept.	16	15	6	Total.	
1595	☉	April	9	Ter. de		Fuego		1607	☉	Feb.	25	21	48	1	13
1595	☽	April	24	4	12	Total		1607	☽	March	13	6	36	1	22
1595	☉	May	7	2	—	*		1607	☉	Sept.	5	15	40	4	7
1595	☉	Oct.	3	2	4	5	18	1608	☉	Feb.	15	at the		Antipo.	
1595	☽	Oct.	18	20	47	Total		1608	☽	July	27	0	30	1	53
1596	☉	March	28		In	Chili		1608	☉	Aug.	9	4	39	0	40
1596	☽	April	12	8	52	6	4	1609	☽	Jan.	19	15	21	10	32
1596	☉	Sept.	21		In	China		1609	☉	Feb.	4	Fuego		5	22
1596	☽	Oct.	6	21	15	3	33	1609	☽	July	16	12	8	Total	
1597	☉	March	16	St. Pet.		Isle		1609	☉	July	30	Canada		4	10
1597	☉	Sept.	11	Picora		9	49	1609	☉	Dec.	26	19	—	5	50
1598	☽	Feb.	20	18	12	10	55	1610	☽	Jan.	9	1	31	Total	
1598	☉	March	6	22	12	11	57	1610	☉	June	20	Java		10	46
1598	☽	Aug.	16	1	15	Total		1610	☽	July	5	16	58	11	13
1598	☉	Aug.	31	Magel.		8	34	1610	☉	Dec.	15	Cyprus		4	50
1599	☽	Feb.	10	18	21	Total		1610	☽	Dec.	29	16	47	4	23
1599	☉	July	22	4	31	8	18	1611	☉	June	10	Califor.		11	30
1599	☽	Aug.	6	——		Total		1612	☽	May	14	10	38	7	22
1600	☉	Jan.	15	Java		11	48	1612	☉	May	29	23	38	7	14
1600	☽	Jan.	30	6	40	2	58	1612	☽	Nov.	8	3	22	9	49
1600	☉	July	10	2	10	5	39	1612	☉	Nov.	22	Magel		9	0
1601	☉	Jan.	4	Ethiop.		9	40	1613	☉	April	20	Magel-		lanica.	

RICCIOLUS's CATALOGUE OF ECLIPSES.

Aft. Chr.		M. and D.	Middle H. M.	Digits eclipsed.	Aft. Chr.		M. and D.	Middle H. M.	Digits eclipsed.
1613	☽	May 4	0 30	Total	1625	☉	March 6	Florida	
1613	☉	May 19	East	Tartary	1625	☽	March 23	14 11	2 11
1613	☉	Oct. 13	South	Amer.	1625	☉	Sept. 1	St. Pe	ter's Isle
1613	☽	Oct. [illegible]	4 19	Total	1625	☽	Sept. 16	11 41	5 6
1614	☉	April 8	N. Gui.	8 44	1626	☉	Feb. 25	Madag	8 27
1614	☽	April 23	17 36	5 25	1626	☽	Aug. 7	7 48	0 25
1614	☉	Oct. 3	0 57	5 2	1626	☉	Aug. 21	In	Mexico
1614	☽	Oct. 17	4 58	4 56	1627	☽	Jan. 30	11 38	10 21
1615	☉	March 29	Goa	10 58	1627	☉	Feb. 15	Magel	lanica
1615	☉	Sept. 2[illegible]	Salom	Isle	1627	☽	July 27	9 4	Total
1616	☽	March [illegible]	1 58	Total	1627	☉	Aug. 11	Tenduc	10 0
1616	☉	March 17	Mexico	6 47	1628	☉	Jan. 6	Tenduc	5 40
1616	☽	Aug. 26	15 35	Total	1628	☽	Jan. 20	10 11	Total
1616	☽	Sept. 10	Magel.	10 33	1628	☉	July 1	C. Good	Hope
1617	☉	Feb. 5	Magel	lanica	1628	☽	July 16	11 26	Total
1617	☽	Feb. 20	1 49	Total	1628	☉	Dec. 25	In Eng	land
1617	☉	March 6	22 —		1629	☽	Jan. 9	1 30	4 27
1617	☉	Aug. 1	Biarmia	*	1629	☉	June 11	Gange	11 25
1617	☽	Aug. 16	9 22	Total	1629	☉	Dec. 14	Peru	10 14
1618	☉	Jan. 26	Magel	lanica	1630	☽	May 25	17 56	6 0
1618	☽	Feb. 9	3 29	2 57	1630	☉	June 10	7 47	9 8
1618	☉	July 21	Mexico	———	1630	☽	Nov. 19	11 24	9 27
1619	☉	Jan. [illegible]	Califor	nia	1630	☉	Dec. 3	N. Gui.	10 19
1619	☽	June 2[illegible]	12 46	5 10	1631	☉	April 30	Antar.	Circle
1619	☉	July 11	Africa	11 39	1631	☽	May 15	8 15	Total
1619	☽	Dec. 20	15 53	10 47	1631	☉	Oct. 24	C. Good	Hope
1620	☉	May 31	Arctic	Circle	1631	☽	Nov. 8	12 0	Total
1620	☽	June 14	13 47	Total	1632	☉	Apr 19	C. Good	Hope
1620	☉	June 29	Magel.	7 20	1632	☽	May 4	1 24	6 35
1620	☽	Dec. 9	6 39	Total	1632	☉	Oct. 13	Mexico	8 37
1620	☉	Dec. 23	Magel	lanica	1632	☽	Oct. 17	12 23	5 31
1621	☉	May 20	14 54	10 44	1633	☽	April 8	5 14	4 30
1621	☽	June 3	19 42	9 53	1633	☉	Oct. 3	Maldiv	Total
1621	☉	Nov. 1[illegible]	Magel	lanica	1634	☽	March 14	9 35	11 18
1621	☽	Nov. 2[illegible]	15 43	3 28	1634	☉	March 28	Japan	10 19
1622	☉	May 10	C. Verd	11 52	1634	☽	Sept. 7	5 0	Total
1622	☉	Nov. [illegible]	Malac	ca In.	1634	☉	Sept 22	C.G.H.	9 54
1623	☽	April 14	7 19	10 54	1635	☉	Feb. 17	Antar.	Circle
1623	☉	April 29	———	———	1635	☽	March 3	9 29	Total
1623	☽	Oct. [illegible]	0 22	8 35	1635	☉	March 18	Mexico	0 16
1623	☉	Oct. 23	Califor.	10 46	1635	☉	Aug. 12	Iceland	5 0
1624	☉	May 1[illegible]	N. Zem.	6 6	1635	☽	Aug. 27	16 4	Total
1624	☽	April [illegible]	7 9	Total	1636	☉	Feb. 6	In	Peru
1624	☉	April 17	Antar.	Circle	1636	☽	Feb. 20	11 34	3 23
1624	☉	Sept. 1[illegible]	Mag	lanica	1636	☉	Aug [illegible]	Tartary	11 20
1624	☽	Sept. 2[illegible]	8 55	Total	1636	☽	Aug. 16	4 34	1 25

RICCIOLUS's CATALOGUE OF ECLIPSES.

Aft. Chr.		M. & D.		Middle H.	M.	Digits eclipsed		Aft. Chr.		M. and D.		Middle H.	M.	Digits eclipsed	
1637	☉	Jan.	26	Cam		boya		1649	☉	June	9	Arct.C.		4	0
1637	☉	July	21	Jucutan				1649	☉	Nov.	4	2	10	3	16
1637	☽	Dec.	31	0	44	10	45	1649	☽	Nov.	18	19	56	Total	
1638	☉	Jan.	14	Persia		9	45	1650	☉	April	30	5	54	—	
1638	☽	June	25	20	17	Total		1650	☽	May	15	8	37	7	57
1638	☉	July	11	{ Mag		9	5	1650	☉	Oct.	24	17	17	—	
1638	☉	Dec.	5	{ ellan		2	10	1650	☽	Nov.	7	20	29	5	3
1638	☽	Dec.	20	15	16	Total		1651	☉	April	19	Tuber.		—	
1639	☉	Jan.	4	Tartary		0	30	1651	☉	Oct.	14	2	15	—	
1639	☉	June	1	5	29	10	40	1652	☽	March	24	16	53	8	50
1639	☽	June	15	2	41	11	9	1652	☉	April	7	22	40	9	59
1639	☉	Nov.	24	Magel.		11	0	1652	☽	Sept.	17	7	27	9	49
1639	☽	Dec.	9	11	57	3	46	1652	☉	Oct.	2	5	2	—	
1640	☉	May	20	N.Spa.		10	30	1653	☉	Feb.	27	—		—	
1640	☉	Nov.	13	Peru 2		10	36	1653	☽	March	13	17	9	Total	
1641	☽	April	25	1		9	43	1653	☉	Aug.	22	—		—	
1641	☉	May	9	Peru		10	16	1653	☽	Sept.	6	23	45	Total	
1641	☽	Oct.	18	8	19	6	31	1654	☉	Feb.	16	[illegible]	10	—	
1641	☉	Nov.	2	18	46	—		1654	☽	March	2	19	25	3	14
1642	☉	March	30	Estod.		4	0	1654	☉	Aug.	11	22	24	2	28
1642	☽	April	14	14	31	Total		1654	☽	Aug.	27	11	40	1	53
1642	☉	Sept.	25	Magel		lanica		1655	☉	Feb.	6	2	37	4	20
1642	☽	Oct.	7	16	45	Total		1655	☉	Aug.	1	14	19	—	
1643	☉	March	19	13	53	—		1655	☽	Aug.	16	16	—	*	
1643	☽	April	3	21	10	3	9	1656	☽	Jan.	11	9	4	10	0
1643	☉	Sept.	12	17	0	—		1656	☽	July	6	3	17	Total	
1643	☽	Sept.	27	7	38	6	0	1656	☉	July	21	11	48	—	
1644	☉	March	8	6	20	—		1656	☽	Dec.	30	23	30	Total	
1644	☉	Aug.	31	18	10	—		1657	☉	June	11	11	20	—	
1645	☽	Feb.	10	7	45	8	52	1657	☽	June	25	9	35	Total	
1645	☉	Feb.	26	Rom.I.		10	46	1657	☉	Dec.	4	20	0	—	
1645	☽	Aug.	7	2	4	Total		1657	☽	Dec.	20	7	47	3	9
1645	☉	Aug.	21	0	35	4	40	1658	☉	May	21	16	0	—	
1646	☉	Jan.	16	Str. of		Anian		1658	☽	June	14	22	58	—	
1646	☽	Jan.	30	18	11	Total		1658	☽	Nov.	9	13	56	0	10
1646	☉	July	12	6	57	—		1658	☉	Nov.	24	11	36	—	
1646	☽	July	27	6	2	Total		1659	☽	May	6	8	34	8	5
1647	☉	Jan.	5	12	10	—		1659	☉	May	20	17	[illegible]	—	
1647	☽	Jan.	20	9	43	4	47	1659	☽	Oct.	29	16	16	5	52
1647	☉	July	2	0	9	—		1659	☉	Nov.	14	[illegible]	25	9	51
1647	☉	Dec.	25	13	38	—		1660	☽	April	21	11	58	Total	
1648	☽	June	5	0	55	4	28	1660	☉	Oct.	3	22	34	—	
1648	☉	June	20	13	23	—		1660	☽	Oct.	18	0	32	Total	
1648	☽	Nov.	29	19	17	7	40	1660	☉	Nov.	2	13	44	—	
1648	☉	Dec.	13	21	48	—		1661	☉	March	29	22	32	—	
1649	☽	May	25	15	20	Total		1661	☽	April	14	4	28	—	

RICCIOLUS's CATALOGUE OF ECLIPSES.

Aft. Chr.		M. and D.		Middle H.	M.	Digits eclipsed	Aft. Chr.		M. and D.		Middle H.	M.	Digits eclipsed
1661	☉	Sept.	23	1	36	11 19	1676	☽	June	25	6	26	——
1661	☽	Oct.	7	14	51	7 4	1676	☉	Dec.	4	20	52	——
1662	☉	March	19	15	8	——	1677	☉	Nov.	24	12	5	——
1662	☉	April	12	1	8	——	1677	☽	May	16	16	25	8 15
1663	☽	Feb.	21	16	11	3 14	1678	☽	May	6	5	30	——
1663	☉	March	9	5	47	——	1678	☽	Oct.	29	9	17	Total
1663	☽	Aug.	18	8	45	Total	1679	☉	April	10	21	0	——
1663	☉	Sept.	1	8	8	——	1679	☽	May	25	11	53	5 47
1664	☉	Jan.	27	20	40	——	1680	☉	March	29	23	22	——
1664	☽	Feb.	11	3	16	——	1680	☉	Sept.	22	7	57	——
1664	☉	July	22	14	48	——	1680	☽	March	4	Noon		——
1664	☉	Aug.	20	22	10	——	1681	☉	March	19	13	43	——
1665	☽	Jan.	30	18	47	4 34	1681	☽	Aug.	28	15	22	10 35
1665	☉	July	12	7	48	——	1681	☉	Sept.	11	15	43	——
1665	☽	July	26	13	31	0 10	1682	☽	Feb.	21	12	28	Total
1666	☉	Jan.	4	21	33	——	1682	☽	Aug.	16	18	56	Total
1666	☉	July	1	19	0	11 10	1683	☉	Jan.	27	1	35	10 30
1667	☽	June	5	Noon		——	1683	☽	Feb.	9	3	39	——
1667	☉	July	21	2	32	——	1683	☽	Aug.	6	20	36	——
1667	☉	Nov.	25	11	30	——	1684	☉	Jan.	16	6	34	——
1668	☉	May	10	Setting		——	1684	☽	June	26	15	18	1 35
1668	☽	May	25	16	26	9 52	1684	☉	July	12	4	26	Total
1668	☉	Nov.	4	2	53	9 50	1684	☽	Dec.	21	11	18	9 45
1668	☽	Nov.*	18	3	54	6 43	1685	☉	Jan.	4	16	0	——
1669	☉	April	29	18	18	——	1685	☽	June	16	6	0	——
1669	☉	Oct.	24	10	13	——	1685	☽	Dec.	10	11	26	Total
1670	☉	April	1[illegible]	7	0	——	1686	☉	May	21	17	9	——
1670	☉	Sept.	10	19	0	——	1686	☽	June	6	Noon		——
1670	☽	Sept.	28	15	45	9 7	1686	☽	Nov.	29	12	22	Total
1670	☉	Oct.	13	12	5	——	1687	☉	May	11	1	—	•
1671	☉	April	8	23	29	——	1687	☽	May	26	14	—	•
1671	☉	Sept.	2	21	25	——	1687	☽	April	15	7	4	6 49
1671	☽	Sept.	18	7	44	Total	1688	☉	April	20	16	27	——
1672	☉	Feb.	28	3	38	——	1688	☽	Oct.	9	Noon		——
1672	☽	March	13	3	17	——	1688	☉	Oct.	25	19	40	——
[illegible]	☉	Aug.	2[illegible]	6	43	——	1689	☽	April	4	7	42	Total
1672	☽	Sept.	[illegible]	18	54	——	1689	☽	Sept.	28	15	46	Total
1673	☉	Feb.	6	7	29	——	1690	☉	March	10	——		——
1673	☉	Aug.	11	21	44	——	1690	☽	March	24	11	14	5 43
1674	☽	Jan.	21	18	22	11 21	1690	☉	Sept.	5	——	——	——
167[illegible]	☉	Feb.	[illegible]	9	4	——	1690	☽	Sept.	18	2	42	——
167[illegible]	☽	July	17	9	40	Total	1691	☉	Feb.	27	17	30	——
167[illegible]	☽	Jan.	11	8	29	Total	169[illegible]	☉	Aug.	22	5	51	——
16[illegible]	☉	Jan.	25	10	36	——	1692	☽	Feb.	2	3	20	——
1675	☽	July	6	16	51	Total	1692	☉	Feb.	17	17	31	——
1676	☉	June	10	21	26	4 34	1692	☽	July	27	16	9	Total

RICCIOLUS's CATALOGUE OF ECLIPSES.

Aft. Chr.		M. and D.	Middle H. M.	Digits eclipsed	Aft. Chr.		M. and D.	Middle H. M.	Digits eclipsed
1693	☽	Jan. 21	17 25	Total	1696	☉	Nov. 23	17 32	———
1693	☽	June 17	Noon	———	1697	☉	April 20	14 32	———
1694	☽	Jan. 11	Noon	———	1697	☽	May 5	18 27	———
1694	☉	June 22	4 22	6 22	1697	☽	Oct. 29	8 44	88 45
1694	☽	July 6	13 51	0 47	1698	☉	April 10	9 13	———
1695	☉	May 11	6 3	———	1698	☉	Oct. 3	15 29	———
1695	☽	May 28	Noon	———	1699	☽	March 15	8 14	9 7
1695	☽	Nov. 20	8 0	6 55	1699	☉	March 30	22 0	———
1695	☉	Dec. 5	17 7	———	1699	☽	Sept. 8	23 22	———
1696	☽	May 16	12 45	Total	1699	☉	Sept. 23	22 38	9 58
1696	☉	May 30	12 56	———	1700	☽	March 4	20 11	———
1696	☽	Nov. 8	17 30	Total	1700	☽	Aug. 29	1 42	———

The Eclipses from Struyk were observed; those from Ricciolus calculated: the following from *L'Art de vérifier les Dates* are only those which are visible in *Europe* for the present century: those which are total are marked with a *T.*; and *M.* signifies Morning, *A.* Afternoon.

VISIBLE ECLIPSES FROM 1700 TO 1800.

Aft. Chr.		Months and Days.	Time of the Day or Night.	Aft. Chr.		Months and Days.	Time of the Day or Night.
1701	☽	Feb. 22	11 A.	1715	☉	May 3	9 M.*T.*
1703	☽	Jan. 3	7 M.	1715	☽	Nov. 11	5 M.
1703	☽	June 29	1 M.*T.*	1717	☽	March 27	3 M.
1703	☽	Dec. 23	7 M.*T.*	1717	☽	May 20	6 A.
1704	☽	Dec. 11	7 M.	1718	☽	Sept. 9	8 A.*T.*
1706	☽	April 28	2 M.	1719	☽	Aug. 29	9 A.
1706	☉	May 12	10 M.	1721	☽	Jan. 13	3 A.
1706	☽	Oct. 21	7 A.	1722	☽	June 29	3 M.
1707	☽	April 17	2 M.*T.*	1722	☉	Dec. 8	3 A.
1708	☽	April 5	6 M.	1722	☽	Dec. 22	4 A.
1708	☉	Dec. 14	8 M.	1724	☉	May 22	7 A.*T.*
1708	☽	Sept. 29	9 A.	1724	☽	Nov. 1	4 M.
1709	☉	March 11	2 A.	1725	☽	Oct. 21	7 A.
1710	☽	Feb. 13	11 A.	1726	☉	Sept. 25	6 A.
1710	☉	Feb. 28	1 A.	1726	☽	Oct. 11	5 M.
1711	☉	July 15	8 A.	1727	☉	Sept. 15	7 M.
1711	☽	July 29	6 A.*T.*	1729	☽	Feb. 13	6 A.*T.*
1712	☽	Jan. 23	8 A.	1729	☽	Aug. 9	1 M.
1713	☽	June 8	6 A.	1730	☽	Feb. 4	4 M.
1713	☽	Dec. 2	4 M.	1731	☽	June 20	2 M.

VISIBLE ECLIPSES FROM 1700 TO 1800.

Aft. Chr.		Months and Days.		Time of the Day or Night.		Aft. Chr.		Months and Days.		Time of the Day or Night.	
1732	☽	Dec.	1	10	A.*T.*	1794	☉	April	1	10	M.
1733	☉	May	13	7	A.	1764	☽	April	16	1	M.
1735	☽	May	28	7	A.	1765	☉	March	21	2	A.
1735	☽	Oct	2	1	M.	1765	☉	Aug.	16	5	A.
1736	☽	March	26	12	A.*T.*	1766	☽	Feb.	24	7	A.
1736	☽	Sept.	20	3	M.*T.*	1766	☉	Aug.	5	7	A.
1736	☉	Oct.	4	6	A.	1768	☽	Jan.	4	5	M.
1737	[illegible]	March	1	4	A.	1768	☽	June	30	4	M.*T.*
1737	☽	Sept.	9	4	M.	1768	☽	Dec.	23	4	A.*T.*
1738	☉	Aug.	15	11	M.	1769	☉	June	4	8	M.
1739	☽	Jan.	24	11	A.	1769	☽	Dec.	15	7	M.
1739	☉	Aug.	4	5	A	1770	[illegible]	Nov.	17	10	M.
1739	☉	Dec.	30	9	M.	1771	☽	April	28	2	M.
1740	☽	Jan.	13	11	A.*T.*	1771	☽	Oct.	23	5	A.
1741	☽	Jan.	1	12	A.	1772	☽	Oct.	11	6	A.*T.*
174[illegible]	☽	Nov.	2	3	M.*T*	1772	[illegible]	Oct.	26	10	M.
174[illegible]	☽	Aug.	26	9	A.	1773	☉	March	23	5	M.
1746	☽	Aug.	30	[illegible]	A.	1773	☽	Sept.	30	7	A.
174[illegible]	☽	Feb.	14	5	M.*T.*	1774	[illegible]	March	12	10	M.
1748	[illegible]	July	25	11	M.	1776	[illegible]	July	31	1	M.*T.*
1748	☽	Aug.	8	13	A.	1776	[illegible]	Aug.	14	5	M.
1749	☽	Dec.	23	8	A.	1777	[illegible]	Jan.	9	5	A.
1750	☉	Jan.	[illegible]	9	M.	1778	☉	June	24	4	A.
1750	☽	June	19	9	A.*T.*	1778	☽	Dec.	4	6	M.
1750	☽	Dec.	[illegible]	7	M.	1779	☽	May	30	5	M.*T.*
1751	☽	June	9	2	M.	1779	[illegible]	June	14	8	M.
1751	☽	Dec.	2	10	A.	1779	☽	Nov.	23	9	A.
1752	[illegible]	May	13	8	A.	1780	[illegible]	Oct.	27	6	A.
1753	☽	Apr.	17	7	A.	1781	☽	Nov.	12	4	M.
175[illegible]	☉	Oct.	26	10	M.	1781	☉	April	2	6	A.
175[illegible]	☽	March	28	1	M.	1782	[illegible]	Oct.	17	8	M.
1757	☽	Feb.	4	5	M.	1783	☽	April	13	7	A.
1757	☽	July	30*	12	A.	1783	☽	March	18	9	A.*T.*
1758	☽	Jan.	24	7	M.*T.*	1783	[illegible]	Sept.	10	11	A.*T.*
1758	☉	Dec.	30	7	M.	1784	☽	March	7	3	M.
1759	☉	June	24	7	A.	1785	☉	Feb.	9	1	A.
1759	☉	Dec.	19	2	A.	1787	☽	Jan.	3	12	A.*T.*
1760	☽	May	29	9	A.	1787	☉	Jan.	19	10	M.
1760	[illegible]	June	13	7	M.	1787	☉	June	15	5	A.
1760	☽	Nov.	23	9	A.	1787	☽	Dec.	24	3	A.
1761	☽	May	18	11	A.*T.*	[illegible]	☉	June	4	9	M.
1762	☽	May	8	4	M.	1789	☽	Nov.	2	12	A.
1762	☉	Oct.	17	8	M.	1790	☽	April	28	12	A.*T.*
1762	☽	Nov.	1	8	A.	1790	☽	Oct.	23	1	M.*T.*
1763	☉	April	13	8	M.	1791	☉	April	3	1	A.

VISIBLE ECLIPSES FROM 1700 TO 1800.

Aft. Chr.		Months and Days.		Time of the Day or Night.		Aft. Chr.		Months and Days.		Time of the Day or Night.	
1791	☽	Oct.	12	3	M.	1795	☽	Feb.	4	1	M.
1792	☉	Sept.	16	11	M.	1795	☉	July	16	9	M.
1793	☽	Feb.	25	10	A.	1795	☽	July	31	8	A.
1793	☉	Sept.	5	3	A.	1797	☉	June	25	8	A.
1794	☉	Jan.	31	4	A.	1797	☽	Dec.	4	6	M.
1794	☽	Feb.	14	11	A.*T.*	1798	☽	May	27	7	A.*T.*
1794	☉	Aug.	25	5	A.	1800	☽	Oct.	2	11	A.

328. *A List of Eclipses, and historical Events, which happened about the same Times, from* RICCIOLUS.

Before CHRIST.			
754	*July*	5	But according to an old calendar, this eclipse of the Sun was on the 21st of *April*, on which day the foundations of *Rome* were laid; if we may believe *Taruntius Firmanus*.
721	*March*	19	A total eclipse of the Moon. The *Assyrian* Empire at an end; the *Babylonian* established.
585	*May*	28	An eclipse of the Sun foretold by THALES, by which a peace was brought about between the *Medes* and *Lydians*. Historical eclipse.
523	*July*	6	An eclipse of the Moon, which was followed by the death of CAMBYSES.
502	*Nov.*	19	An eclipse of the Moon, which was followed by the slaughter of the *Sabines*, and death of *Valerius Publicola*.
463	*April*	30	An eclipse of the Sun. The *Persian* war, and the falling-off of the *Persians* from the *Egyptians*

Before CHRIST.		
431	*April* 25	An eclipse of the Moon, which was followed by a great famine at *Rome;* and the beginning of the *Peloponnesian* war.
431	*August* 3	A total eclipse of the Sun. A comet and plague at *Athens**.
413	*August* 27	A total eclipse of the Moon. *Nicias* with his ship destroyed at *Syracuse.*
394	*August* 14	An eclipse of the Sun. The *Persians* beat by *Conon* in a sea-engagement.
168	*June* 21	A total eclipse of the Moon. The next day *Perseus* King of *Macedonia* was conquered by *Paulus Emilius.*

After CHRIST.		
59	*April* 30	An eclipse of the Sun. This is reckoned among the prodigies, on account of the murder of *Agrippinus* by *Nero.*
237	*April* 12	A total eclipse of the Sun. A sign that the reign of the *Gordiani* would not continue long. A sixth persecution of the Christians.
306	*July* 27	An eclipse of the Sun. The stars were seen, and the Emperor *Constantius* died.
840	*May* 4	A dreadful eclipse of the Sun. And *Lewis* the Pious died within six months after it.
1009	———	An eclipse of the Sun. And *Jerusalem* taken by the *Saracens.*
1133	*August* 2	A terrible eclipse of the Sun. The stars were seen. A schism in the church, occasioned by there being three Popes at once.

* This eclipse happened in the first year of the Peloponnesian war.

329. I have not cited one half of RICCIOLUS's list of portentous eclipses; and for the same reason that he declines giving any more of them than what that list contains; namely, that it is most disagreeable to dwell any longer on such nonsense, and as much as possible to avoid tiring the reader: the superstition of the ancients may be seen by the few here copied. My author farther says, that there were treatises written to shew against what regions the malevolent effects of any particular eclipse was aimed; and the writers affirmed, that the effects of an eclipse of the Sun continued as many years as the eclipse lasted hours; and that of the Moon as many months.

The superstitious notions of the ancients with regard to eclipses.

330. Yet such idle notions were once of no small advantage to CHRISTOPHER COLUMBUS, who, in the year 1493, was driven on the island of *Jamaica*, where he was in the greatest distress for want of provisions, and was moreover refused any assistance from the inhabitants; on which he threatened them with a plague, and told them, that in token of it, there should be an eclipse. This accordingly fell on the day he had foretold, and so terrified the Barbarians, that they strove who should be first in bringing him all sorts of provisions; throwing them at his feet, and imploring his forgiveness. RICCIOLUS's *Almagest*, Vol. I. l. v. c. ii.

Very fortunate once for CHRISTOPHER COLUMBUS.

331. Eclipses of the Sun are more frequent than those of the Moon, because the Sun's ecliptic-limits are greater than the Moon's, § 317: yet we have more visible eclipses of the Moon than of the Sun, because eclipses of the Moon are seen from all parts of that hemisphere of the Earth which is next her, and are equally great to each of those parts; but the Sun's eclipses are visible only to that small portion of the hemisphere next him whereon the Moon's shadow falls, as shall be explained by and by at large.

Why there are more visible eclipses of the Moon than of the Sun.

332. The Moon's orbit being elliptical, and the Earth in one of its focuses, she is once at her least

Plate XI. Fig. I.

distance from the earth, and once at her greatest, in every lunation. When the Moon changes at her least distance from the Earth, and so near the node that her dark shadow falls upon the Earth, she appears big enough to cover the whole * disc of the Sun from that part on which her shadow falls; and the Sun appears totally eclipsed there, as at *A*, for some minutes: but when the Moon changes at her greatest distance from the Earth, and so near the node that her dark shadow is directed toward the earth, her diameter subtends a less angle than the Sun's; and therefore she cannot hide his whole disc from any part of the Earth, nor does her shadow reach it at that time; and to the place over which the point of her shadow hangs, the eclipse is annular, as at *B*; the Sun's edge appearing like a luminous ring all around the body of the Moon. When the change happens within 17 degrees of the node, and the Moon at her mean distance from the Earth, the point of her shadow just touches the Earth, and she eclipses the Sun totally to that small spot whereon her shadow falls; but the darkness is not of a moment's continuance.

Total and annular eclipses of the Sun.

The longest duration of total eclipses of the Sun.

333. The Moon's apparent diameter, when largest, exceeds the Sun's when least, only 1 minute 38 seconds of a degree: and in the greatest eclipse of the Sun that can happen at any time and place, the total darkness continues no longer than while the Moon is going 1 minute 38 seconds from the Sun in her orbit; which is about 3 minutes and 13 seconds of an hour.

To how much of the Earth the Sun may be totally or partially eclipsed at once.

334. The Moon's dark shadow covers only a spot on the Earth's surface, about 180 *English* miles broad, when the Moon's diameter appears largest,

* Although the Sun and Moon are spherical bodies, as seen from the Earth they appear to be circular planes; and so would the Earth do, if it were seen from the Moon. The apparently flat surfaces of the Sun and Moon are called their *discs* by astronomers.

and the Sun's least; and the total darkness can extend no farther than the dark shadow covers. Yet the Moon's partial shadow or penumbra may then cover a circular space 4900 miles diameter, within all which the Sun is more or less eclipsed, as the places are less or more distant from the centre of the penumbra. When the Moon changes exactly in the node, the penumbra is circular on the Earth at the middle of the general eclipse; because at that time it falls perpendicularly on the Earth's surface: but at every other moment it falls obliquely, and will therefore be elliptical, and the more so, as the time is longer before or after the middle of the general eclipse; and then, much greater portions of the Earth's surface are involved in the penumbra. *Plate XI.*

335. When the penumbra first touches the Earth, the general eclipse begins: when it leaves the Earth, the general eclipse ends: from the beginning to the end the Sun appears eclipsed in some part of the Earth or other. When the penumbra touches any place, the eclipse begins at that place, and ends when the penumbra leaves it. When the Moon changes in the node, the penumbra goes over the centre of the Earth's disc as seen from the Moon; and consequently by describing the longest line possible on the Earth, continues the longest upon it; namely, at a mean rate, 5 hours 50 minutes: more, if the Moon be at her greatest distance from the Earth, because she then moves slowest; less, if she be at her least distance, because of her quicker motion. *Duration of general and particular eclipses.*

336. To make the last five articles and several other phenomena plainer, let *S* be the Sun, *E* the Earth, *M* the Moon, and *AMP* the Moon's orbit. Draw the right line *Wc* 12 from the western side of the Sun at *W*, touching the western side of the Moon at *c*, and the Earth at 12: draw also the right line *Vd* 12 from the eastern side of the Sun at *V*, touching the eastern side of the Moon at *d*, and the *Fig. II.*

The Moon's dark shadow,

Earth at 12: the dark space *ce* 12 *d* included between those lines in the Moon's shadow, ending in a point at 12, where it touches the Earth; because in this case the Moon is supposed to change at *M* in the middle between *A* the apogee, or farthest point of her orbit from the Earth, and P the perigee, or nearest point to it. For, had the point *P* been at *M*, the Moon had been nearer the Earth; and her dark shadow at *e* would have covered a space upon it about 180 miles broad, and the Sun would have been totally darkened, as at *A* (Fig. I,) with some continuance: but had the point *A* (Fig. II,) been at *M*, the Moon would have been farther from the Earth, and her shadow would have ended in a point about *e*, and therefore the Sun would have appeared, as at *B* (Fig. I.), like a luminous ring all around the Moon.

and penumbra.

Draw the right lines *W X d h* and *V X c g*, touching the contrary sides of the Sun and Moon, and ending on the Earth at *a* and *b*: draw also the right line *S X M* 12, from the centre of the Sun's disc, through the Moon's centre, to the Earth at 12; and suppose the two former lines *W X d h* and *V X c g* to revolve on the line *S X M* 12 as an axis, and their points *a* and *b* will describe the limits of the penumbra *TT* on the Earth's surface, including the large space *a* 0 *b* 12 *a*, within which the Sun appears more or less eclipsed, as the places are more or less distant from the verge of the penumbra *a* 0 *b*.

Digits, what.

Draw the right line *y* 12 across the Sun's disc, perpendicular to *S X M*, the axis of the penumbra: then divide the line *y* 12 into twelve equal parts, as in the figure, for the twelve * digits of the Sun's diameter: and at equal distances from the centre of the penumbra at 12 (on the Earth's surface *YY*) to its edge *a* 0 *b*, draw twelve concentric circles, as marked with the numeral figures 1, 2, 3, 4, &c. and

* A digit is a twelfth part of the diameter of the Sun or Moon.

remember that the Moon's motion in her orbit *A M P* is from west to east, as from *s* to *t*. Then, *Plate XI.*

To an observer on the Earth at *b*, the eastern limb of the Moon at *d* seems to touch the western limb of the Sun at *W*, when the Moon is at *M*; and the Sun's eclipse begins at *b*, appearing as at *A* in Fig. III, at the left hand; but at the same moment of absolute time to an observer at *a* in Fig. II, the western edge of the Moon at *c* leaves the eastern edge of the Sun at *V*, and the eclipse ends, as at the right hand *C* of Fig. III. At the very same instant, to all those who live on the circle marked 1 on the Earth *E* in Fig. II. the Moon *M* cuts off or darkens a twelfth part of the Sun *S*, and eclipses him one digit, as at 1 in Fig. III: to those who live on the circle marked 2 in Fig. II, the Moon cuts off two twelfth parts of the Sun, as at 2 in Fig. III: to those on the circle 3, three parts; and so on to the centre at 12 in Fig. II, where the Sun is centrally eclipsed as at *B* in the middle of Fig. III; under which figure there is a scale of hours and minutes, to shew, at a mean rate, how long it is from the beginning to the end of a central eclipse of the Sun on the parallel of *London*; and how many digits are eclipsed at any particular time from the beginning at *A* to the middle at *B*, or the end at *C*. Thus, in 16 minutes from the beginning, the Sun is two digits eclipsed; in an hour and five minutes, eight digits; and in an hour and thirty-seven minutes, 12 digits.

The different phases of a solar eclipse.

Fig. III.

337. By Fig. II, it is plain, that the Sun is totally or centrally eclipsed but to a small part of the Earth at any time; because the dark conical shadow *e* of the Moon *M* falls but on a small part of the Earth: and that a partial eclipse is confined at that time to the space included by the circle *a* O *b*, of which only one half can be projected in the figure, the other half being supposed to be hid by the convexity of the Earth *E*: and likewise, that no part Fig. II.

Plate XI. of the Sun is eclipsed to the large space *YY* of the Earth, because the Moon is not between the Sun and any of that part of the Earth: and therefore to all that part the eclipse is invisible.

The velocity of the Moon's shadow on the Earth

The Earth turns eastward on its axis, as from *g* to *h*, which is the same way that the Moon's shadow moves; but the Moon's motion is much swifter in her orbit from *s* to *t*: and therefore, although eclipses of the Sun are of longer duration on account of the Earth's motion on its axis than they would be if that motion was stopt, yet in four minutes of time at most the Moon's swifter motion carries her dark shadow quite over any place that its centre touches at the time of greatest obscuration. The motion of the shadow on the Earth's disc is equal to the Moon's motion from the Sun, which is about 30½ minutes of a degree every hour at a mean rate; but so much of the Moon's orbit is equal to 30½ degrees of a great circle on the Earth, § 320; and therefore the Moon's shadow goes 30½ degrees or 1830 geographical miles on the Earth in an hour, or 30½ miles in a minute, which is almost four times as swift as the motion of a cannon ball.

Fig. IV.

338. As seen from the Sun or Moon, the Earth's axis appears differently inclined every day of the year, on account of keeping its parallelism throughout its annual course. Let *E*, *D*, *O*, *N*, be the Earth at the two equinoxes, and the two solstices, *NS* its axis, *N* the north pole, *S* the south pole, *ÆQ* the equator, *T* the tropic of Cancer, *t* the tropic of Capricorn, and *A B C* the circumference of the Earth's enlightened disc as seen from the Sun or new Moon at these times.

Phenomena of the Earth as seen from the Sun or new Moon at different times of the year.

The Earth's axis has the position *N E S* at the vernal equinox, lying toward the right hand, as seen from the Sun or new Moon; its poles *N* and *S* being then in the circumference of the disc; and the equator and all its parallels seem to be straight lines, because their planes pass through the observer's eye looking down upon the Earth from the Sun or Moon directly over *E*, where the ecliptic *FG* intersects the

equator *Æ Q*. At the summer solstice, the Earth's axis has the position *NDS;* and that part of the ecliptic *F G*, in which the Moon is then new, touches the tropic of Cancer *T* at *D*. The north pole *N* at that time inclining 23½ degrees toward the Sun, falls so many degrees within the Earth's enlightened disc, because the Sun is then vertical to *D*, 23½ degrees north of the equator *Æ Q;* and the equator, with all its parallels seem elliptic curves bending downward, or toward the south pole, as seen from the Sun: which pole, together with 23½ degrees all round it, is hid behind the disc in the dark hemisphere of the Earth. At the autumnal equinox, the Earth's axis has the position *NOS*, lying to the left hand as seen from the Sun or new Moon, which are then vertical to *O*, where the ecliptic cuts the equator *Æ Q*. Both poles now lie in the circumference of the disc, the north pole just going to disappear behind it, and the south pole just entering into it; and the equator with all its parallels seem to be straight lines, because their planes pass through the observer's eye, as seen from the Sun, and very nearly so as seen from the Moon. At the winter solstice, the Earth's axis has the position *N N S ;* when its south pole *S* inclining 23½ degrees towards the Sun, falls 23½ degrees within the enlightened disc, as seen from the Sun or new Moon, which are then vertical to the tropic of Capricorn *t*, 23½ degrees south of the equator *Æ Q;* and the equator with all its parallels seem elliptic curves bending upward; the north pole being as far behind the disc in the dark hemisphere, as the south pole is come into the light. The nearer that any time of the year is to the equinoxes or solstices, the more it partakes of the phenomena relating to them.

339. Thus it appears, that from the vernal equinox to the autumnal, the north pole is enlightened; and the equator and all its parallels appear elliptical as seen from the Sun, more or less curved as the time is nearer to or farther from the summer sol-

Plate XI. Various positions of the Earth's axis as seen from the Sun at different times of the year.

stice; and bending downward, or toward the south pole; the reverse of which happens from the autumnal equinox to the vernal. A little consideration will be sufficient to convince the reader, that the Earth's axis inclines toward the Sun at the summer solstice; from the Sun at the winter solstice; and sidewise to the Sun at the equinoxes; but toward the right hand, as seen from the Sun at the vernal equinox; and toward the left hand at the autumnal. From the winter to the summer solstice, the Earth's axis inclines more or less to the right hand, as seen from the Sun; and the contrary from the summer to the winter solstice.

How these positions affect solar eclipses.

340. The different positions of the Earth's axis, as seen from the Sun at different times of the year, affect solar eclipses greatly with regard to particular places; yea so far as would make central eclipses which fall at one time of the year, invisible if they had fallen at another; even though the Moon should always change in the nodes, and at the same hour of the day: of which indefinitely various affections, we shall only give examples for the times of the equinoxes and solstices.

Fig. IV.

In the same diagram, let *F G* be part of the ecliptic, and *I K*, *i k*, *i k*, *i k*. part of the Moon's orbit; both seen edgewise, and therefore projected into right lines; and let the intersections *N*, *O*, *D*, *E*, be one and the same nodes at the above times, when the Earth has the forementioned different positions; and let the space included by the circles, *P*, *p*, *p*, *p*, be the penumbra at these times, as its centre is passing over the centre of the Earth's disc. At the winter solstice, when the Earth's axis has the position *N N S*, the centre of the penumbra *P* touches the tropic of Capricorn *t* in *N* at the middle of the general eclipse; but no part of the penumbra touches the tropic of Cancer *T*. At the summer solstice, when the Earth's axis has the position *N D S* (*i D k*

being then part of the Moon's orbit, whose node is at *D*), the penumbra *p* has its centre at *D*, on the tropic of Cancer *T*, at the middle of the general eclipse, and then no part of it touches the tropic of Capricorn *t*. At the autumnal equinox, the Earth's axis has the position *N O S* (*i O k* being then part of the Moon's orbit), and the penumbra equally includes part of both tropics *T* and *t* at the middle of the general eclipse: at the vernal equinox it does the same, because the Earth's axis has the position *N E S*: but in the former of these two last cases, the penumbra enters the Earth at *A*, north of the tropic of Cancer *T*, and leaves it at *m*, south of the tropic of Capricorn *t*; having gone over the Earth obliquely southward, as its centre described the line *A O m*: whereas, in the latter case, the penumbra touches the Earth at *n*, south of the equator *Æ Q*, and describing the line *n E q* (similar to the former line *A O m* in open space) goes obliquely northward over the earth, and leaves it at *q*, north of the equator.

In all these circumstances, the Moon has been supposed to change at noon in her descending node: had she changed in her ascending node, the phenomena would have been as various the contrary way, with respect to the penumbra's going northward or southward over the Earth. But because the Moon changes at all hours, as often in one node as in the other, and at all distances from them both at different times as it happens, the variety of the phases of eclipses are almost innumerable, even at the same places; especially considering how variously the same places are situate on the enlightened disc of the Earth, with respect to the penumbra's motion, at the different hours when eclipses happen.

341. When the Moon changes 17 degrees short of her descending node, the penumbra *P* 18 just touches the northern part of the Earth's disc, near How much of the penumbra falls on the

Earth at different distances from the nodes. the north pole N; and as seen from that place the Moon appears to touch the Sun, but hides no part of him from sight. Had the change been as far short of the ascending node; the penumbra would have touched the southern part of the disc near the south pole S. When the Moon changes 12 degrees short of the descending node, more than a third part of the penumbra P 12 falls on the northern parts of the Earth at the middle of the general eclipse: had she changed as far past the same node, as much on the other side of the penumbra about P would have fallen on the southern part of the Earth; all the rest in the *expansum* or open space. When the Moon changes 6 degrees from the node, almost the whole penumbra P 6 falls on the Earth at the middle of the general eclipse. And lastly, when the Moon changes in the node at N, the penumbra $P\,N$ takes the longest course possible on the Earth's disc; its centre falling on the middle of it, at the middle of the general eclipse. The farther the Moon changes from either node, within 17 degrees of it, the shorter is the penumbra's continuance on the Earth, because it goes over a less proportion of the disc, as is evident by the figure.

The Earth's diurnal motion lengthens the duration of solar eclipses, which fall without the polar circles.

342. The nearer that the penumbra's centre is to the equator at the middle of the general eclipse, the longer is the duration of the eclipse at all those places where it is central; because, the nearer that any place is to the equator the greater is the circle it describes by the Earth's motion on its axis; and so, the place moving quicker, keeps longer in the penumbra, whose motion is the same way with that of the place, though faster, as has been already mentioned, § 337. Thus (see the Earth at D and the penumbra at 12) while the point b in the polar circle $a\,b\,c\,d$ is carried from b to c by the Earth's diurnal motion, the point d on the tropic of Cancer T is carried a much greater length from d to D:

and therefore, if the penumbra's centre should go one time over *c*, and another time over *D*, the penumbra will be longer in passing over the moving-place *d*, than it was in passing over the moving-place *b*. Consequently, central eclipses about the poles are of the shortest duration; and about the equator of the longest.

343. In the middle of summer, the whole frigid zone, included by the polar circle *a b c d*, is enlightened; and if it then happens that the penumbra's centre passes over the north pole, the Sun will be eclipsed much the same number of digits at *a* as at *c*; but while the penumbra moves eastward over *c*, it moves westward over *a*, because, with respect to the penumbra, the motions of *a* and *c* are contrary: for *c* moves the same way with the penumbra toward *d*, but *a* moves the contrary way toward *b*; and therefore the eclipse will be of longer duration at *c* than at *a*. At *a*, the eclipse begins on the Sun's eastern limb, but at *c*, on his western: at all places lying without the polar circles, the Sun's eclipses begin on his western limb, or near it, and end on or near his eastern. At those places where the penumbra touches the earth, the eclipse begins with the rising Sun, on the top of his western or uppermost edge; and at those places where the penumbra leaves the Earth, the eclipse ends with the setting Sun, on the top of his eastern edge, which is then the uppermost, just at its disappearing on the horizon.

and shortens the duration of some which fall within these circles.

344. If the Moon were surrounded by an atmosphere of any considerable density, it would seem to touch the Sun a little before the Moon made her appulse to his edge, and we should see a little faintness on that edge before it was eclipsed by the Moon: but as no such faintness has been observed, at least so far as I have ever heard, it seems plain, that the Moon has no such atmosphere as that of the Earth. The faint ring of light surrounding the Sun in to-

The Moon has no atmosphere.

Plate XI. tal eclipses, called by Cassini *la Chevelure du Soleil*, seems to be the atmosphere of the Sun; because it has been observed to move equally with the Sun, not with the Moon.

345. Having said so much about eclipses of the Sun, we shall drop that subject at present, and proceed to the doctrine of lunar eclipses: which, being more simple, may be explained in less time.

Eclipses of the Moon. That the Moon can never be eclipsed but at the time of her being full, and the reason why she is not eclipsed at every full, has been shewn already, Fig. II. § 316, 317. Let *S* be the Sun, *E* the Earth, *RR* the Earth's shadow, and *B* the Moon in opposition to the Sun: in this situation the Earth intercepts the Sun's light in its way to the Moon: and when the Moon touches the Earth's shadow at *v*, she begins to be eclipsed on her eastern limb *x*, and continues eclipsed until her western limb *y* leaves the shadow at *w*; at *B* she is in the middle of the shadow, and consequently in the middle of the eclipse.

346. The Moon when totally eclipsed is not invisible, if she be above the horizon, and the sky be clear; but appears generally of a dusky colour like tarnished copper, which some have thought to be Why the Moon is visible in a total eclipse. the Moon's native light. But the true cause of her being visible is the scattered beams of the Sun, bent into the Earth's shadow by going through the atmosphere; which, being more dense near the Earth than at considerable heights above it, refracts or bends the Sun's rays more inward, § 179; and those which pass nearest the Earth's surface, are bent more than those rays which go through higher parts of the atmosphere, where it is less dense, until it be so thin or rare as to lose its refractive power. Let the circle *f g h i*, concentric to the Earth, include the atmosphere, whose refractive power vanishes at the heights *f* and *i*; so that the rays *W f w* and *V i v*

go on straight without suffering the least refraction. *Plate XI.* But all those rays which enter the atmosphere, between *f* and *k*, and between *i* and *l*, on opposite sides of the Earth, are gradually more bent inward as they go through a greater portion of the atmosphere, until the rays *W k* and *V l* touching the Earth at *m* and *n*, are bent so much as to meet at *q*, a little short of the Moon; and therefore the dark shadow of the Earth is contained in the space *m o q p n*, where none of the Sun's rays can enter: all the rest *R R*, being mixed by the scattered rays which are refracted as above, is in some measure enlightened by them; and some of those rays falling on the Moon, give her the colour of tarnished copper, or of iron almost red-hot. So that if the Earth had no atmosphere, the Moon would be as invisible in total eclipses as she is when new. If the Moon were so near the Earth as to go into its dark shadow, suppose about *p o*, she would be invisible during her stay in it; but visible before and after in the fainter shadow *R R*.

Why the Sun and Moon are sometimes visible when the Moon is totally eclipsed.

347. When the Moon goes through the centre of the Earth's shadow, she is directly opposite to the Sun: yet the Moon has been often seen totally eclipsed in the horizon when the Sun was also visible in the opposite part of it: for, the horizontal refraction being almost 34 minutes of a degree, § 181, and the diameter of the Sun and Moon being each at a mean state but 32 minutes, the refraction causes both luminaries to appear above the horizon when they are really below it, § 179.

348. When the Moon is full at 12 degrees from either of her nodes, she just touches the Earth's shadow, but enters not into it. Let *G H* be the ecliptic, *e f* the Moon's orbit where she is 12 degrees from the node at her full; *c d* her orbit where she is 6 degrees from the node; *a b* her orbit where she is full in the node; *A B* the Earth's shadow, and *M* Fig. V.

Duration of central eclipses of the Moon. the Moon. When the Moon describes the line *e f*, she just touches the shadow, but does not enter into it; when she describes the line *c d*, she is totally, though not centrally immersed in the shadow; and when she describes the line *a b*, she passes by the node at *M* in the centre of the shadow; and takes the longest line possible, which is a diameter, through it: and such an eclipse being both total and central is of the longest duration, namely, 3 hours 57 minutes 6 seconds from the beginning to the end, if the Moon be at her greatest distance from the Earth; and 3 hours 37 minutes 26 seconds, if she be at her least distance. The reason of this difference is, that when the Moon is farthest from the Earth, she moves the slowest; and when nearest to it, the quickest.

Digits. 349. The Moon's diameter, as well as the Sun's, is supposed to be divided into twelve equal parts, called *digits;* and so many of these parts as are darkened by the Earth's shadow, so many digits is the Moon eclipsed. All that the Moon is eclipsed above 12 digits, shew, how far the shadow of the Earth is over the body of the Moon, on that edge to which she is nearest at the middle of the eclipse.

Why the beginning and end of a lunar eclipse is so difficult to be determined by observation. 350. It is difficult to observe exactly either the beginning or ending of a lunar eclipse, even with a good telescope; because the Earth's shadow is so faint and ill-defined about the edges, that when the Moon is either just touching or leaving it, the obscuration of her limb is scarce sensible; and therefore the nicest observers can hardly be certain to several seconds of time. But both the beginning and ending of solar eclipses are visibly instantaneous: for the moment that the edge of the Moon's disc touches the Sun's, his roundness seems a little broken on that part; and the moment she leaves it, he appears perfectly round again.

The use of eclipses in astronomy, 351. In astronomy, eclipses of the Moon are of great use for ascertaining the periods of her motions;

especially such eclipses as are observed to be alike in all circumstances, and have long intervals of time between them. In geography, the longitudes of places are found by eclipses, as already shewn in the eleventh chapter. In chronology, both solar and lunar eclipses serve to determine exactly the time of any past event: for there are so many particulars observable in every eclipse, with respect to its quantity, the places where it is visible (if of the Sun,) and the time of the day or night; that it is impossible there can be two solar eclipses in the course of many ages which are alike in all circumstances.

geography, and chronology.

352. From the above explanation of the doctrine of eclipses, it is evident that the darkness at our SAVIOUR's crucifixion was supernatural. For he suffered on the day on which the passover was eaten by the *Jews*, on which day it was impossible that the Moon's shadow could fall on the Earth; for the *Jews* kept the passover at the time of full Moon: nor does the darkness in total eclipses of the Sun last above four minutes in any place, § 333, whereas the darkness at the crucifixion lasted three hours, *Matt.* xxviii. 15. and overspread at least all the land of *Judea*.

The darkness at our SAVIOUR's crucifixion supernatural.

CHAP. XIX.

Shewing the Principles on which the following Astronomical Tables are constructed, and the Method of calculating the Times of New and Full Moons and Eclipses by them.

358. THE nearer that any object is to the eye of an observer, the greater is the angle under which it appears: the farther from the eye, the less.

The diameters of the Sun and Moon subtend different angles at different times. And at equal intervals of time, these angles are once at the greatest, and once at the least, in somewhat more than a complete revolution of the luminary through the ecliptic, from any given fixed star to the same star again.—This proves that the Sun and Moon are constantly changing their distances from the Earth; and that they are once at their greatest distance and once at their least, in little more than a complete revolution.

The gradual differences of these angles are not what they would be, if the luminaries moved in circular orbits, the Earth being supposed to be placed at some distance from the centre: but they agree perfectly with elliptic orbits, supposing the lower focus of each orbit to be at the centre of the Earth.*

The farthest point of each orbit from the Earth's centre is called the *apogee*, and the nearest point is called the *perigee*.—These points are directly opposite to each other.

Astronomers divide each orbit into 12 equal parts called *signs*; each sign into 30 equal parts, called *degrees*; each degree into 60 equal parts, called *minutes*; and every minute into 60 equal parts, called *seconds*. The distance of the Sun or Moon from

* The Sun is in the focus of the Earth's orbit, and the Earth in or near that of the Moon's orbit.

any given point of its orbit, is reckoned in signs, degrees, minutes, and seconds. Here we mean the distance that the luminary has moved through from any given point; not the space it is short of it in coming round again, though ever so little.

The distance of the Sun or Moon from its apogee at any given time is called its *mean anomaly:* so that, in the apogee, the anomaly is nothing; in the perigee, it is six signs.

The motions of the Sun and Moon are observed to be continually accelerated from the apogee to the perigee, and as gradually retarded from the perigee to the apogee; being slowest of all when the mean anomaly is nothing, and swiftest of all when it is six signs.

When the luminary is in its apogee or its perigee, its place is the same as it would be, if its motion were equable in all parts of its orbit.—The supposed equable motions are called *mean;* the unequable are justly called the *true.*

The mean place of the Sun or Moon is always forwarder than the true place*, while the luminary is moving from its apogee to its perigee; and the true place is always forwarder than the mean, while the luminary is moving from its perigee to its apogee.—In the former case, the anomaly is always less than six signs; and in the latter case, more.

It has been found, by a long series of observations, that the Sun goes through the ecliptic, from the *vernal equinox* to the same equinox again, in 365 days 5 hours 48 minutes 55 seconds: from the *first star of Aries* to the same star again, in 365 days 6 hours 9 minutes 24 seconds: and from his *apogee* to the same again, in 365 days 6 hours 14 minutes 0 seconds.—The first of these is called the *solar*

* The point of the ecliptic in which the Sun or Moon is at any given moment of time is called the *place* of the Sun or Moon at that time.

year, the second the *sidereal* year, and the third the *anomalistic year*. So that the solar year is 20 minutes 29 seconds shorter than the sidereal; and the sidereal year is 4 minutes 36 seconds shorter than the anomalistic.—Hence it appears that the *equinoctial point*, or intersection if the ecliptic and equator at the beginning of Aries, goes backward with respect to the fixed stars, and that the Sun's apogee goes forward.

It is also observed, that the Moon goes through her orbit from any given fixed star to the same star again, in 27 days 7 hours 43 minutes 4 seconds at a mean rate: from her apogee to her apogee again, in 27 days 13 hours 18 minutes 43 seconds: and from the Sun to the Sun again, in 29 days 12 hours 44 minutes $3\frac{1}{10}$ seconds. This shews, that the Moon's apogee moves forward in the ecliptic, and *that* at a much quicker rate than the Sun's apogee does; since the Moon is 5 hours 55 minutes 39 seconds longer in revolving from her apogee to her apogee again, than from any star to the same star again.

The Moon's orbit crosses the ecliptic in two opposite points, which are called her *nodes*: and it is observed that she revolves sooner from any node to the same node again, than from any star to the same star again, by 2 hours 38 minutes 27 seconds; which shews that her nodes move backward, or contrary to the order of signs, in the ecliptic.

The time in which the Moon revolves from the Sun to the Sun again (or from change to change) is called a *lunation*; which, according to Dr. POUND's mean measures, would always consist of 29 days 12 hours 44 minutes 3 seconds 2 thirds 58 fourths, if the motions of the Sun and Moon were always equable*.—Hence, 12 mean lunations contain 354 days

* We have thought proper to keep by Dr. *Pound*'s length of a mean lunation, because his numbers come nearer to the times of the ancient eclipses, than *Mayer*'s do, without allowing for the Moon's acceleration.

8 hours 48 minutes 36 seconds 35 thirds 40 fourths, which is 10 days 21 hours 11 minutes 23 seconds 24 thirds 20 fourths less than the length of a common *Julian year*, consisting of 365 days 6 hours; and 13 mean lunations contain 383 days 21 hours 32 minutes 39 seconds 38 thirds 38 fourths, which exceeds the length of a common *Julian year*, by 18 days 15 hours 32 minutes 39 seconds 38 thirds 38 fourths.

The mean time of new Moon being found for any given year and month, as suppose for *March* 1700, old style, if this mean new Moon falls later than the 11th day of *March*, then 12 mean lunations, added to the time of this mean new Moon, will give the time of the mean new Moon in *March* 1701, after having thrown off 365 days.—But when the mean new Moon happens to be before the 11th of *March*, we must add 13 mean lunations, in order to have the time of mean new Moon in *March* the year following; always taking care to subtract 365 days in common years, and 366 days in leap-years, from the sum of this addition.

Thus, *A. D.* 1700, old style, the time of mean new Moon in *March*, was the 8th day, at 16 hours 11 minutes 25 seconds after the noon of that day (*viz.* at 11 minutes 25 seconds past IV in the morning of the 9th day, according to common reckoning). To this we must add 13 mean lunations, or 383 days 21 hours 32 minutes 39 seconds 38 thirds 38 fourths, and the sum will be 392 days 13 hours 44 minutes 4 seconds 38 thirds 38 fourths; from which subtract 365 days, because the year 1701 is a common year, and there will remain 27 days 13 hours 44 minutes 4 seconds 38 thirds 38 fourths for the time of mean new Moon in *March*, *A. D.* 1701.

Carrying on this addition and subtraction till *A. D.* 1703, we find the time of mean new Moon in *March* that year, to be on the 6th day at 7 hours

21 minutes 17 seconds 49 thirds 46 fourths past noon; to which add 13 mean lunations, and the sum will be 390 days 4 hours 53 minutes 57 seconds 28 thirds 20 fourths; from which subtract 366 days, because the year 1704 is a leap-year, and there will remain 24 days 4 hours 53 minutes 57 seconds 28 thirds 20 fourths for the time of mean new Moon in *March. A. D.* 1704.

In this manner was the first of the following tables constructed to seconds, thirds, and fourths; and then written out to the nearest second.—The reason why we chose to begin the year with *March*, was to avoid the inconvenience of adding a day to the tabular time in leap-years after *February*, or subtracting a day therefrom in *January* and *February* in those years; to which all tables of this kind are subject, which begin the year with *January*, in calculating the times of new or full Moons.

The mean anomalies of the Sun and Moon, and the Sun's mean motion from the ascending node of the Moon's orbit, are set down in Table III. from one to 13 mean lunations.—These numbers, for 13 lunations, being added to the radical anomalies of the Sun and Moon, and to the Sun's mean distance from the ascending node, at the time of mean new Moon in *March* 1700, (Table I.) will give their mean anomalies, and the Sun's mean distance from the node, at the time of mean new Moon in *March* 1701; and being added for 12 lunations to those for 1701, give them for the time of mean new Moon in *March* 1702. And so on, as far as you please to continue the table (which is here carried on to the year 1800), always throwing off 12 signs when their sum exceeds 12, and setting down the remainder as the proper quantity.

If the numbers belonging to *A. D.* 1700 (in Table I.) be subtracted from those belonging to 1800, we shall have their whole differences in 100 complete Julian years; which accordingly we find to be

4 days 8 hours 10 minutes 52 seconds 15 thirds 40 fourths, with respect to the time of mean new Moon.—These being added together 60 times, (always taking care to throw off a whole lunation when the days exceed 29½) making up 60 centuries, or 6000 years, as in Table VI. which was carried on to seconds, thirds, and fourths; and then written out to the nearest second. In the same manner were the respective anomalies and the Sun's distance from the node found, for these centurial years; and then (for want of room) written out only to the nearest minute, which is sufficient in whole centuries.—By means of these two tables, we may find the time of any mean new Moon in *March*, together with the anomalies of the Sun and Moon, and the Sun's distance from the node, at these times, within the limits of 6000 years, either before or after any given year in the 18th century; and the mean time of any new or full Moon in any given month after *March*, by means of the third and fourth tables, within the same limits, as shewn in the precepts for calculation.

Thus it would be a very easy matter to calculate the time of any new or full Moon, if the Sun and Moon moved equably in all parts of their orbits.—But we have already shewn that their places are never the same as they would be by equable motions, except when they are in apogee or perigee; which is when their mean anomalies are either nothing, or six signs: and that their mean places are always forwarder than their true places, while the anomaly is less than six signs; and their true places are forwarder than the mean, while the anomaly is more.

Hence it is evident, that while the Sun's anomaly is less than six signs, the Moon will overtake him, or be opposite to him, sooner than she could if his motion were equable; and later while his anomaly is more than six signs. The greatest difference that can possibly happen between the mean and true time

of new or full Moon, on account of the inequality of the Sun's motion, is three hours 48 minutes 28 seconds: and that is, when the Sun's anomaly is either 3 signs 1 degree, or 8 signs 29 degrees; sooner in the first case, and later in the last.—In all other signs and degrees of anomaly, the difference is gradually less, and vanishes when the anomaly is either nothing or six signs.

The Sun is in his apogee on the 30th of *June*, and in his perigee on the 30th of *December*, in the present age; so that he is nearer the Earth in our winter than in our summer. The proportional difference of distance, deduced from the difference of the Sun's apparent diameter at these times, is as 983 to 1017.

The Moon's orbit is dilated in winter, and contracted in summer; therefore the lunations are longer in winter than in summer. The greatest difference is found to be 22 minutes 29 seconds; the lunations increasing gradually in length while the Sun is moving from his apogee to his perigee, and decreasing in length while he is moving from his perigee to his apogee.—On this account the Moon will be later every time in coming to her conjunction with the Sun, or being in opposition to him, from *December* till *June*, and sooner from *June* to *December*, than if her orbit had continued of the same size all the year round.

As both these differences depend on the Sun's anomaly, they may be fitly put together into one table, and called *The annual, or first equation of the mean to the true* syzygy* (see Table VII.) This equational difference is to be subtracted from the time of the mean syzygy when the Sun's anomaly is less than six signs, and added when the anomaly is more.—At the greatest, it is 4 hours 10 minutes 57 seconds, *viz.* 3 hours 48 minutes 28 seconds,

* The word *syzygy* signifies both the conjunction and opposition of the Sun and Moon.

on account of the Sun's unequal motion, and 22 minutes 29 seconds, on account of the dilatation of the Moon's orbit.

This compound equation would be sufficient for reducing the mean time of new or full Moon to the true time, if the Moon's orbit were of a circular form, and her motion quite equable in it.—But the Moon's orbit is more elliptical than the Sun's, and her motion in it so much the more unequal. The difference is so great, that she is sometimes in conjunction with the Sun, or in opposition to him, sooner by 9 hours 47 minutes 54 seconds, than she would be if her motion were equable; and at other times as much later.—The former happens when her mean anomaly is 9 signs 4 degrees, and the latter when it is 2 signs 26 degrees. *See* Table IX.

At different distances of the Sun from the Moon's apogee, the figure of the Moon's orbit becomes different.—It is longest of all, or most eccentric, when the Sun is in the same sign and degree either with the Moon's apogee or perigee; shortest of all, or least eccentric, when the Sun's distance from the Moon's apogee is either three signs or nine signs; and at a mean state when the distance is either 1 sign 15 degrees, 4 signs 15 degrees, 7 signs 15 degrees, or 10 signs 15 degrees.—When the Moon's orbit is at its greatest eccentricity, her apogeal distance from the Earth's centre is to her perigeal distance from it, as 1067 is to 933; when least eccentric, as 1043 is to 957; and when at the mean state, as 1055 is to 945.

But the Sun's distance from the Moon's apogee is equal to the quantity of the Moon's mean anomaly at the time of new Moon, and by the addition of six signs, it becomes equal in quantity to the Moon's mean anomaly at the time of full Moon.—Therefore, a table may be constructed so as to answer all the various inequalities depending on the different eccentricities of the Moon's orbit in the syzygies; and called *The second equation of the mean to the true*

syzygy (see Table IX.) and the Moon's anomaly, when equated by Table VIII. may be made the proper argument for taking out this second equation of time, which must be added to the former equated time, when the Moon's anomaly is less than six signs, and subtracted when the anomaly is more.

There are several other inequalities in the Moon's motion, which sometimes bring on the true syzygy a little sooner, and at other times keep it back a little later than it would otherwise be; but they are so small, that they may be all omitted except two; the former of which (*see* Table X.) depends on the difference between the anomalies of the Sun and Moon in the syzygies, and the latter (*see* Table XI.) depends on the Sun's distance from the Moon's nodes at these times. The greatest difference arising from the former, is 4 minutes 58 seconds; and from the latter, 1 minute 34 seconds.

Having described the phenomena arising from the inequalities of the solar and lunar motions, we shall now shew the reasons of these inequalities.

In all calculations relating to the Sun and Moon, we consider the Sun as a moving body, and the Earth as a body at rest; since all the appearances are the same, whether it be the Sun or the Earth that moves. But the truth is, that the Sun is at rest, and the Earth moves round him once a year, in the plane of the ecliptic. Therefore, whatever sign and degree of the ecliptic the Earth is in, at any given time, the Sun will then appear to be in the opposite sign and degree.

The nearer that any body is to the Sun, the more it is attracted by him; and this attraction increases as the square of the distance diminishes; and *vice versâ*.

The Earth's annual orbit is elliptical, and the Sun is placed in one of its focuses. The remotest point

of the Earth's orbit from the Sun is called *The earth's aphelion;* and the nearest point of the Earth's orbit to the Sun, is called *The Earth's perihelion.*—When the Earth is in its aphelion, the Sun appears to be in its apogee; and when the Earth is in its perihelion, the Sun appears to be in its perigee.

As the Earth moves from its aphelion to its perihelion, it is constantly more and more attracted by the Sun; and this attraction, by conspiring in some degree with the Earth's motion, must necessarily accelerate it. But as the Earth moves from its perihelion to its aphelion, it is continually less and less attracted by the Sun; and as this attraction acts then just as much against the Earth's motion, as it acted for it in the other half of the orbit, it retards the motion in the like degree.—The faster the Earth moves, the faster will the Sun appear to move; the slower the Earth moves, the slower is the Sun's apparent motion.

The Moon's orbit is also elliptical, and the Earth keeps constantly in one of its focuses.—The Earth's attraction has the same kind of influence on the Moon's motion, as the Sun's attraction has on the motion of the Earth: and therefore, the Moon's motion must be continually accelerated while she is passing from her apogee to her perigee; and as gradually retarded in moving from her perigee to her apogee.

At the time of new Moon, the Moon is nearer the Sun than the Earth is at that time, by the whole semidiameter of the Moon's orbit; which, at a mean state, is 240,000 miles; and at the full, she is as much farther from the Sun than the Earth then is.—Consequently, the Sun attracts the Moon more than it attracts the Earth in the former case, and less in the latter. The difference is greatest when the Earth is nearest the Sun, and least when it is farthest from him. The obvious result of this is, that as the Earth is nearest to the Sun in winter,

and farthest from him in summer, the Moon's orbit must be dilated in winter, and contracted in summer.

These are the principal causes of the difference of time, that generally happens between the mean and true times of conjunction or opposition of the Sun and Moon. As to the other two differences, *viz.* those which depend on the difference between the anomalies of the Sun and Moon, and upon the Sun's distance from the lunar nodes, in the syzygies, they are owing to the different degrees of attraction of the Sun and Earth upon the Moon, at greater or less distances, according to their respective anomalies, and to the position of the Moon's nodes with respect to the Sun.

If ever it should happen, that the anomalies of both the Sun and Moon were either nothing or six signs, at the mean time of new or full Moon, and the Sun should then be in conjunction with either of the Moon's nodes, all the above-mentioned equations would vanish, and the mean and true time of the syzygy would coincide. But if ever this circumstance did happen, we cannot expect the like again in many ages afterward.

Every 49th lunation (or course of the Moon from change to change) returns very nearly to the same time of the day as before. For, in 49 mean lunations there are 1446 days 23 hours 58 minutes 29 seconds 25 thirds, which wants but 1 minute 30 seconds 34 thirds of 1477 days.

In 2953059085108 days, there are 100000000000 mean lunations exactly: and this is the smallest number of natural days in which any exact number of mean lunations will be completed.

TABLE I. *The mean Time of New Moon in* March, *Old Style, with the mean Anomalies of the Sun and Moon, and the Sun's mean Distance from the Moon's Ascending Node, from* A. D. 1700 *to* A. D. 1800 *inclusive.*

Y. of Chr.	Mean New Moon in March.				Sun's mean Anomaly.				Moon's mean Anomaly.				Sun's mean Dist. from the Node.			
	D.	H.	M.	S.	s	°	′	″	s	°	′	″	s	°	′	″
1700	8	16	11	25	8	19	58	48	1	22	30	37	6	14	31	7
1701	27	13	44	5	9	8	20	59	0	28	7	42	7	23	14	8
1702	16	22	32	41	8	27	36	51	11	7	55	47	8	1	16	55
1703	6	7	21	18	8	16	52	43	9	17	43	52	8	9	19	42
1704	24	4	53	57	9	5	14	54	8	23	20	57	9	18	2	43
1705	13	13	42	34	8	24	30	47	7	3	9	2	9	26	5	30
1706	2	22	31	11	8	13	46	39	5	12	57	7	10	4	8	17
1707	31	20	3	50	9	2	8	50	4	18	34	13	11	12	51	18
1708	10	4	52	27	8	21	24	43	2	28	22	18	11	20	54	5
1709	29	2	25	7	9	9	46	54	2	3	59	24	0	29	37	6
1710	18	11	13	43	8	29	2	47	0	13	47	30	1	7	39	54
1711	7	20	2	20	8	18	18	39	10	23	35	36	1	15	42	41
1712	25	17	34	59	9	6	40	51	9	29	12	42	2	14	25	43
1713	15	2	23	36	8	25	56	43	8	9	0	47	3	2	28	30
1714	4	11	12	13	8	15	12	35	6	18	48	52	3	10	31	17
1715	23	8	44	52	9	3	34	47	5	24	25	57	4	19	14	18
1716	11	17	33	29	8	22	50	39	4	4	14	2	4	27	17	5
1717	1	2	22	5	8	12	6	32	2	14	2	8	5	5	19	52
1718	19	23	54	45	9	0	28	44	1	19	39	13	6	14	2	54
1719	9	8	43	22	8	19	44	37	11	29	27	18	6	22	5	41
1720	27	6	16	1	9	8	6	49	11	5	4	24	8	0	48	43
1721	16	15	4	38	8	27	22	41	9	14	52	29	8	8	51	29
3722	5	23	53	14	8	16	38	33	7	24	40	34	8	16	54	16
1723	24	21	25	54	9	5	0	45	7	0	17	40	9	25	37	18
1724	13	6	14	31	8	24	16	37	5	10	5	45	10	3	40	5
1725	2	15	3	7	8	13	32	29	3	19	53	50	10	11	42	52
1726	21	12	35	47	9	1	54	41	2	25	30	56	11	20	25	54
1727	10	21	24	23	8	21	10	34	1	5	19	1	11	28	28	41
1728	28	18	57	3	9	9	52	46	0	10	50	7	1	7	11	42
1729	18	3	45	40	8	28	48	39	10	20	44	12	1	15	14	29
1730	7	12	34	16	8	18	4	31	9	0	32	17	1	23	17	16
1731	26	10	6	56	9	6	26	42	8	6	9	23	3	2	0	17
1732	14	18	55	33	8	25	42	34	6	15	57	28	3	10	3	4

TABLE I, *continued.* *Old Style.*

Y. of Chr.	Mean New Moon in March.				Sun's mean Anomaly.				Moon's mean Anomaly.				Sun's mean Dis. from the Node.			
	D.	H.	M.	S.	s	°	′	″	s	°	′	″	s	°	′	″
1733	4	3	44	9	8	14	58	26	4	25	45	33	3	18	5	51
1734	23	1	16	49	9	3	20	38	4	1	22	39	4	26	48	53
1735	12	10	3	25	8	22	36	30	2	11	10	44	5	4	51	40
1736	0	18	54	2	8	11	52	22	0	20	58	49	5	12	54	27
1737	19	16	26	42	9	0	14	34	11	26	35	55	6	21	37	29
1738	9	1	15	18	8	19	30	26	10	6	24	0	6	29	40	16
1739	27	22	47	58	9	7	52	38	9	12	1	6	8	8	23	18
1740	16	7	36	34	8	27	8	30	7	21	49	11	8	16	26	5
1741	5	16	25	11	8	16	24	22	6	1	37	16	8	24	28	52
1742	24	13	57	52	9	4	46	34	5	7	14	22	10	3	11	54
1743	13	22	46	27	8	24	2	27	3	17	2	27	10	1	14	41
1744	2	7	35	4	8	13	18	20	1	26	50	32	10	19	17	28
1745	21	5	7	44	9	1	40	32	1	2	27	38	11	28	0	30
1746	10	13	56	20	8	20	56	24	11	12	15	43	0	6	3	17
1747	29	11	29	0	9	9	18	36	10	17	52	49	1	14	46	19
1748	17	20	17	36	8	28	34	28	8	27	40	54	1	22	49	5
1749	7	5	6	13	8	17	50	20	7	7	28	59	2	0	51	52
1750	26	2	38	53	9	6	12	32	6	13	6	5	3	9	34	53
1751	15	11	27	29	8	25	28	24	4	22	54	10	3	17	37	40
1752	3	20	16	6	8	14	44	16	3	2	42	15	3	35	40	27
1753	22	17	48	45	9	3	6	28	2	8	19	21	5	4	23	28
1754	12	2	37	22	8	22	22	20	0	18	7	26	5	12	26	15
1755	1	11	25	59	8	11	38	12	10	27	55	31	5	20	29	2
1756	19	8	58	38	9	0	0	24	10	3	32	37	6	29	12	3
1757	8	17	47	15	8	19	16	16	8	13	20	42	7	7	14	50
1758	27	15	19	54	9	7	38	28	7	28	57	48	8	15	57	52
1759	17	0	8	31	8	26	54	20	5	28	45	54	8	24	0	39
1760	5	8	57	8	8	16	10	12	4	8	34	6	9	2	3	26
1761	24	6	29	47	9	4	32	24	3	14	11	6	10	10	46	27
1762	13	15	18	24	8	23	48	16	1	23	59	11	10	18	49	14
1763	3	0	7	1	8	13	4	8	0	3	47	16	10	26	52	1
1764	20	21	39	40	9	1	26	20	11	9	24	21	0	5	35	2
1765	10	6	28	17	8	20	42	13	9	19	12	26	0	13	37	49
1766	29	4	0	56	9	9	4	20	8	24	49	32	1	22	20	51

TABLE I, *concluded.* *Old Style.*

Y. of Chr.	Mean New Moon in March.				Sun's mean Anomaly.				Moon's mean Anomaly.				Sun's mean Dist. from the Node.			
	D.	H.	M.	S.	s	0	′	″	s	0	′	″	s	0	′	″
1767	18	12	49	33	8	28	20	17	7	4	37	37	2	0	23	38
1768	6	21	38	10	8	17	36	9	5	14	25	42	2	8	26	25
1769	25	19	10	40	9	5	58	21	4	20	2	48	3	17	9	27
1770	15	3	59	26	8	25	14	13	2	29	50	53	3	25	12	14
1771	4	12	48	2	8	14	30	5	1	9	38	58	4	3	15	1
1772	22	10	20	43	9	2	52	17	0	15	16	4	5	11	58	3
1773	11	19	9	19	8	22	8	9	10	25	4	9	5	20	0	50
1774	1	3	57	55	8	11	24	1	9	4	52	14	5	28	3	37
1775	20	1	30	25	8	29	46	13	8	10	29	20	7	6	49	38
1776	8	10	19	12	8	19	2	5	6	20	17	25	7	14	49	25
1777	27	7	51	51	9	7	24	17	5	25	54	31	8	23	32	26
1778	16	16	40	28	8	26	40	9	4	5	42	36	9	1	35	13
1779	6	1	29	4	8	15	56	1	2	15	30	41	9	9	38	0
1780	23	23	1	44	9	4	18	13	1	21	7	47	10	18	21	1
1781	13	7	50	21	8	23	34	5	0	0	55	52	10	26	23	48
1782	2	16	38	57	8	12	49	58	10	10	43	57	11	4	26	35
1783	21	14	11	37	9	1	12	10	9	16	21	3	0	13	9	36
1784	9	23	0	13	8	20	28	3	7	26	9	8	0	21	12	23
1785	28	20	32	53	9	8	50	15	7	1	46	14	1	29	55	25
1786	18	5	21	30	8	28	6	7	5	11	34	19	2	7	58	12
1787	7	14	10	6	8	17	21	59	3	21	22	24	2	16	0	59
1788	25	11	42	46	9	5	44	11	2	26	59	30	3	24	44	1
1789	14	20	31	23	8	25	0	3	1	6	47	35	4	2	46	48
1790	4	5	19	59	8	14	15	55	11	16	35	40	4	10	49	35
1791	23	2	52	39	9	2	38	7	10	22	12	46	5	19	32	37
1792	11	11	41	15	8	21	53	59	9	2	0	52	5	27	35	24
1793	30	9	13	55	9	10	16	11	8	7	37	58	7	6	18	26
1794	19	18	2	32	8	29	32	3	6	17	26	4	7	14	21	13
1795	9	2	51	8	8	18	47	55	4	27	14	9	7	22	24	0
1796	27	0	23	48	9	7	10	7	4	2	51	14	9	1	7	1
1797	16	9	12	24	8	26	25	59	2	12	39	19	9	9	9	48
1798	5	18	1	1	8	15	41	51	0	22	27	25	9	17	12	35
1799	24	15	23	41	9	4	4	3	11	28	4	31	10	25	55	37
1800	13	0	22	17	8	23	19	55	10	7	52	36	11	3	58	22

TABLE II. *Mean New Moon, &c. in* March, *New Style, from* A. D. 1752 *to* A. D. 1800.

Y. of Chr.	Mean New Moon in March.				Sun's mean Anomaly.				Moon's mean Anomaly.				Sun's mean Dist. from the Node.			
	D.	H.	M.	S.	s	°	′	″	s	°	′	″	s	°	′	″
1752	14	20	16	6	8	14	44	16	3	2	42	15	3	25	40	27
1753	4	5	4	42	8	4	0	8	1	12	30	20	4	3	43	14
1754	23	2	37	22	8	22	22	20	0	18	7	26	5	12	26	15
1755	12	11	25	59	8	11	38	12	10	27	55	31	5	20	29	2
1756	30	8	58	38	9	0	0	24	10	3	32	37	6	29	12	3
1757	19	17	47	15	8	19	16	16	8	13	20	42	7	7	14	50
1758	9	2	35	51	8	8	32	8	6	23	8	47	7	15	17	38
1759	28	0	8	31	8	26	54	20	5	28	45	54	8	24	0	39
1760	16	8	57	8	8	16	10	12	4	8	34	0	9	2	3	26
1761	5	17	45	44	8	5	26	4	2	18	22	5	9	10	6	13
1762	24	15	18	24	8	23	48	16	1	23	59	11	10	18	49	14
1763	14	0	7	1	8	13	4	8	0	3	47	16	10	26	52	1
1764	2	8	55	36	8	2	20	0	10	13	35	21	11	4	54	48
1765	21	6	28	17	8	20	42	13	9	19	12	26	0	13	37	49
1766	10	15	16	53	8	9	58	5	7	29	0	31	0	21	40	37
1767	29	12	49	33	8	28	20	17	7	4	37	37	2	0	23	38
1768	17	21	38	9	8	17	36	9	5	14	25	42	2	8	26	25
1769	7	6	26	46	8	6	52	1	3	24	13	47	2	16	29	13
1770	26	3	59	26	8	25	14	13	2	29	50	53	3	25	12	14
1771	15	12	48	2	8	14	30	5	1	9	38	58	4	3	15	1
1772	3	21	36	39	8	3	45	57	11	19	27	3	4	11	17	48
1773	22	19	9	19	8	22	8	9	10	25	4	9	5	20	0	50
1774	12	3	57	55	8	11	24	1	9	4	52	14	5	28	3	37
1775	1	12	46	31	8	0	39	53	7	14	40	19	6	6	6	24
1776	19	10	19	12	8	19	2	5	6	20	17	25	7	14	49	25
1777	8	19	7	48	8	8	17	57	5	0	5	30	7	22	52	12
1778	27	16	40	28	8	26	40	9	4	5	42	36	9	1	35	13
1779	17	1	29	4	8	15	56	1	2	15	30	41	9	9	38	0
1780	5	10	17	40	8	5	11	53	0	25	18	46	9	17	40	47
1781	24	7	50	21	8	23	34	5	0	0	55	52	10	26	23	48
1782	13	16	38	57	8	12	49	58	10	10	43	57	11	4	26	35
1783	3	1	27	33	8	2	5	50	8	20	32	2	11	12	29	22
1784	20	23	0	33	8	20	28	3	9	26	9	8	0	21	12	23
1785	10	7	48	50	8	9	43	55	6	5	57	13	0	29	15	10
1786	29	5	21	30	8	28	6	7	5	11	34	19	2	7	58	12

TABLE II, *concluded. New Style.*

Y. of Chr.	Mean New Moon in March.				Sun's mean Anomaly.				Moon's mean Anomaly.				Sun's mean Dis. from the Node.			
	D.	H.	M.	S	s	°	′	″	s	°	′	″	s	°	′	″
1787	18	14	10	6	8	17	21	59	3	21	22	24	2	16	9	59
1788	6	22	58	42	8	6	37	51	2	1	10	29	2	24	3	46
1789	25	20	31	23	8	25	0	3	1	6	47	35	4	2	46	48
1790	15	5	19	59	8	14	15	55	11	16	35	40	4	10	49	35
1791	4	14	8	35	8	3	31	47	9	26	23	45	4	18	52	22
1792	22	11	41	15	8	21	53	59	9	2	0	52	5	27	35	24
1793	11	20	29	51	8	11	9	51	7	11	48	57	6	5	31	11
1794	30	18	2	33	8	29	32	3	6	17	26	4	7	14	21	13
1795	20	2	51	6	8	18	47	55	4	27	14	9	7	22	24	0
1796	8	11	39	44	8	8	3	47	3	7	2	14	8	0	26	47
1797	27	9	12	24	8	26	25	59	2	12	39	19	9	9	9	48
1798	16	18	1	1	8	15	41	51	0	22	27	25	9	17	12	35
1799	6	2	49	57	8	4	57	43	11	2	15	30	9	25	15	22
1800	25	0	22	17	8	23	19	55	10	7	52	36	11	3	58	25

TABLE III. *Mean Anomalies, and Sun's mean Distance from the Node, for 13½ mean Lunations.*

No.	Mean Lunations.				Sun's mean Anomaly.				Moon's mean Anomaly.				Sun's mean Dis. from the Node.			
	D.	H.	M	S	s	°	′	″	s	°	′	″	s	°	′	″
1	29	12	44	3	0	29	6	19	0	25	49	0	1	0	40	14
2	59	1	28	6	1	28	12	39	1	21	38	1	2	1	20	28
3	88	14	12	9	2	27	18	58	2	17	27	1	3	2	0	42
4	118	2	56	12	3	26	25	17	3	13	16	2	4	2	40	56
5	147	15	40	15	4	25	31	37	4	9	5	2	5	3	21	10
6	177	4	14	18	5	24	37	56	5	4	54	3	6	4	1	24
7	206	17	8	21	6	23	44	15	6	0	43	3	7	4	41	38
8	36	5	52	24	7	22	50	35	6	26	32	3	8	5	21	52
9	265	18	36	27	8	21	56	54	7	22	21	4	9	6	2	6
10	295	7	20	30	9	21	3	14	8	18	10	4	10	6	42	20
11	324	20	[illegible]	33	10	20	9	33	9	3	59	5	11	7	22	34
12	354	8	48	36	11	19	15	52	10	9	48	5	0	8	2	47
13	383	21	32	40	0	18	22	12	11	5	37	6	1	8	43	1
½	14	18	22	2	0	14	33	10	6	12	54	36	0	15	20	7

TABLE IV. *The Days of the Year, reckoned from the Beginning of* March.

Days.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	January.	February.
1	1	32	62	93	123	154	185	215	246	276	307	338
2	2	33	63	94	124	155	186	216	247	277	308	339
3	3	34	64	95	125	156	187	217	248	278	309	340
4	4	35	65	96	126	157	188	218	249	279	310	341
5	5	36	66	97	127	158	189	219	250	280	311	342
6	6	37	67	98	128	159	190	220	251	281	312	343
7	7	38	68	99	129	160	191	221	252	282	313	344
8	8	39	69	100	130	161	192	222	253	283	314	345
9	9	40	70	101	131	162	193	223	254	284	315	346
10	10	41	71	102	132	163	194	224	255	285	316	347
11	11	42	72	103	133	164	195	225	256	286	317	348
12	12	43	73	104	134	165	196	226	257	287	318	349
13	13	44	74	105	135	166	197	227	258	288	319	350
14	14	45	75	106	136	167	198	228	259	289	320	351
15	15	46	76	107	137	168	199	229	260	290	321	352
16	16	47	77	108	138	169	200	230	261	291	322	353
17	17	48	78	109	139	170	201	231	262	292	323	354
18	18	49	79	110	140	171	202	232	263	293	324	355
19	19	50	80	111	141	172	203	233	264	294	325	356
20	20	51	81	112	142	173	204	234	265	295	326	357
21	21	52	82	113	143	174	205	235	266	296	327	358
22	22	53	83	114	144	175	206	236	267	297	328	359
23	23	54	84	115	145	176	207	237	268	298	329	360
24	24	55	85	116	146	177	208	238	269	299	330	361
25	25	56	86	117	147	178	209	239	270	300	331	362
26	26	57	87	118	148	179	210	240	271	301	332	363
27	27	58	88	119	149	180	211	241	272	302	333	364
28	28	59	89	120	150	181	212	242	273	303	334	365
29	29	60	90	121	151	182	213	243	274	304	335	366
30	30	61	91	122	152	183	214	244	275	305	336	
31	31.		92		153	184		245		306	337	

TABLE V. *Mean Lunations from* 1 *to* 100000.

Lunat.	Days, Decimal Parts.		Days.	Hou.	M.	S.	Th.	Fo.
1	29.520590851080	=	29	12	44	3	2	58
2	59.061181702160		59	1	28	6	5	57
3	88.591772553240		88	14	12	9	8	55
4	118.122363404320		118	2	56	12	11	53
5	147.652954255401		147	15	40	15	14	52
6	177.183545106481		177	4	24	18	17	50
7	206.714135957561		206	17	8	21	20	48
8	236.244726808641		236	5	52	24	23	47
9	265.775317659722		265	18	36	27	26	45
10	295.30590851080		295	7	20	30	29	43
20	590.61181702160		590	14	41	0	59	26
30	885.91772553240		885	22	1	31	29	10
40	1181.22363404320		1181	5	22	1	58	53
50	1476.52954255401		1476	12	42	32	28	36
60	1771.83545106481		1771	20	3	2	58	19
70	2067.14135957561		2067	3	23	33	28	2
80	2362.44726808641		2362	10	[illegible]	[illegible]	57	46
90	2657.75317659722		2657	18	[illegible]	34	27	29
100	2953.0590851080		2953	1	25	[illegible]	57	[illegible]
200	5906.1181702160		5906	2	50	9	54	24
300	8859.1772553240		8859	4	15	14	51	36
400	11812.2363404320		11812	5	40	19	48	48
500	14765.2954255401		14765	7	5	24	[illegible]	0
600	17718.3545106481		17718	8	30	29	43	12
700	20671.4135957561		20671	9	55	34	40	24
800	23624.4726808641		23624	11	20	39	37	36
900	26577.5317659722		26577	12	45	44	34	48
1000	29530.590851080		29530	14	10	49	32	0
2000	59061.181702160		59061	4	21	39	4	0
3000	88591.772553140		88591	18	32	28	36	0
4000	118122.363404320		118122	8	43	18	8	0
5000	147652.954255401		147652	22	54	7	40	0
6000	177183.545106481		177183	13	[illegible]	57	12	0
7000	206714.135957561		206714	3	15	46	44	0
8000	236244.726801641		236244	17	26	36	16	0
9000	265775.317659722		265775	7	37	25	48	0
10000	295305.90851080		295305	21	[illegible]	15	20	0
20000	590611.81702160		590611	19	36	30	40	0
30000	885917.72553240		885917	17	24	46	0	0
40000	1188223.63404320		1188223	15	13	1	20	0
50000	1476529.54255401		1476529	13	1	16	40	0
60000	1771835.45106481		1771835	10	49	32	0	0
70000	2067141.35957561		2067141	8	37	47	20	0
80000	2362447.26808641		2362447	6	25	2	40	0
90000	2657753.17659722		2657753	4	14	18	0	0
100000	2953959.0851080		2953959	2	2	[illegible]	20	0

TABLE VI. *The first mean New Moon, with the mean Anomalies of the Sun and Moon, and the Sun's mean Distance from the Ascending [illegible], next after complete Centuries of Julian Years.*

Lunations.	Julian Years.	First New Moon D.	H.	M.	S.	Sun's mean Anomaly s	°	′	Moon's mean Anomaly s	°	′	Sun from Node s	°	′
1237	100	4	8	10	52	0	3	21	8	15	22	4	19	27
2474	200	8	16	21	44	0	6	42	5	0	44	9	8	55
3711	300	13	0	32	37	0	10	3	1	16′	6	1	28	22
4948	400	17	8	43	29	0	13	24	10	1	28	6	17	49
6185	500	21	16	54	21	0	16	46	6	16	50	11	7	16
7422	600	26	1	5	14	0	20	7	3	2	12	3	26	44
8658	700	0	20	32	3	11	24	22	10	21	45	7	15	31
9895	800	5	4	42	55	11	27	34	7	7	7	0	4	58
11132	900	9	12	53	47	0	1	4	3	22	29	4	24	25
12369	1000	13	21	4	40	0	4	25	0	7	51	9	13	53
13606	1100	18	5	15	32	0	7	46	8	23	13	2	3	20
14843	1200	22	13	26	24	0	11	7	5	8	35	6	22	47
16080	1300	26	21	37	16	0	14	28	1	23	57	11	12	15
17316	1400	1	17	4	6	11	18	43	9	13	30	3	1	2
18553	1500	6	1	14	58	11	22	4	5	28	52	7	20	29
19790	1[illegible]00	10	9	25	50	11	25	25	2	14	14	0	9	56
2102[illegible]	1[illegible]00	14	17	36	42	11	28	46	10	29	36	4	29	23
222[illegible]	1800	19	1	47	35	0	2	8	7	14	58	9	18	51
23501	1900	23	9	58	27	0	5	29	4	0	20	2	8	18
24738	2000	27	18	9	19	0	8	50	0	15	42	6	27	45
25[illegible]74	2100	2	13	36	8	11	13	5	8	5	15	10	16	32
27211	2200	6	21	47	1	11	16	26	4	20	37	3	6	0
28448	2300	11	5	57	53	11	19	47	1	5	59	7	25	27
29[illegible]	2400	15	14	8	45	11	23	8	9	21	21	0	14	54
30[illegible]22	2500	19	22	19	[illegible]	[illegible]	2[illegible]	29	6	6	43	5	4	22
32159	2600	24	6	30	[illegible]	[illegible]	29	50	2	22	4	9	23	49
33396	2700	28	14	41	[illegible]	[illegible]	3	11	11	7	26	2	13	16
34632	2[illegible]	3	10	8	[illegible]	11	7	76	6	26	59	6	2	3
358[illegible]	[illegible]	7	18	19	[illegible]	11	10	47	3	12	21	10	21	30
371[illegible]	[illegible]00	12	2	29	56	11	14	8	11	27	43	3	10	58
3834[illegible]	[illegible]00	16	10	40	[illegible]8	11	17	30	8	13	5	8	0	25
395[illegible]0	3200	20	18	51	[illegible]0	11	20	51	4	28	27	0	19	52

TABLE VI. *concluded.*

Lunations.	Julian years.	First New Moon. D.	H	M.	S.	Sun's mean Anomaly. s	°	′	Moon's mean Anomaly. s	°	′	Sun's mean Dis. from Node s	°	′
40817	3300	25	3	2	33	11	24	12	1	13	49	5	9	20
42054	3400	29	11	13	25	11	27	33	9	29	11	9	28	47
43290	3500	4	6	40	14	11	1	48	5	18	44	1	17	34
44527	3600	8	14	51	6	11	5	0	2	4	6	6	7	1
45764	3700	12	23	1	59	11	8	30	10	19	28	10	26	29
47001	3800	17	7	12	51	11	11	51	7	4	50	3	15	56
48238	3900	21	15	23	43	11	15	12	3	20	12	8	5	23
4947[illegible]	[illegible]	25	23	34	35	11	18	33	0	5	34	0	24	50
50711	4100	0	19	1	27	10	22	48	7	25	7	4	13	37
51948	4200	5	3	12	17	10	26	9	4	10	29	9	3	5
53185	4300	6	11	23	9	10	29	31	0	25	51	1	22	32
544[illegible]2	4400	13	19	34	1	11	2	52	9	11	13	6	11	59
55659	4500	18	3	44	54	11	6	13	5	26	3[illegible]	11	1	27
56896	4600	22	11	55	46	11	9	34	2	11	57	3	20	54
58133	4700	26	20	6	38	11	12	55	10	27	19	8	10	21
59369	4800	1	15	33	27	10	17	0	6	16	52	11	29	8
606[illegible]	4900	5	23	44	20	10	20	31	3	2	[illegible]	4	18	36
61843	5000	10	7	55	12	10	23	52	11	17	30	9	8	3
63080	5100	14	16	6	4	10	27	13	8	2	58	1	27	30
64317	520[illegible]	19	0	16	56	11	0	34	4	18	26	6	16	57
655[illegible]	[illegible]	23	8	27	[illegible]	11	3	55	1	3	42	11	6	25
66791	5400	27	16	38	41	11	7	16	9	19	4	2	25	52
68028	5500	2	12	5	30	10	11	31	5	8	37	7	14	39
6[illegible]265	[illegible]	6	20	16	22	10	14	52	1	23	59	0	4	6
[illegible]502	[illegible]	11	4	27	15	10	18	14	10	9	21	4	23	34
[illegible]1739	5803	15	12	38	7	10	21	35	6	24	43	9	13	1
72976	5900	19	20	48	59	10	24	56	3	10	5	2	2	28
74212	6000	24	4	59	52	10	28	17	11	25	27	6	21	56

If Dr. *Pound*'s mean Lunation (which we have kept by in making these tables) be added 74212 times to itself, the sum will amount to 6000 Julian years 24 days 4 hours 59 minutes 51 seconds 40 thirds; agreeing with the first part of the last line of this table, within half a second.

TABLE VII. *The annual, or first Equation of the mean to the true Syzygy.*

Argument. Sun's mean Anomaly.

Subtract

Degrees	0 Sign.			1 Sign.			2 Signs.			3 Signs.			4 Signs.			5 Signs.			Degrees
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	
0	0		0	2	3	12	3	35	0	4	10	53	3	39	30	2	7	45	30
1	0	4	18	2	6	55	3	37	10	4	10	57	3	37	19	2	3	55	29
2	0	8	33	2	10	36	3	39	18	4	10	55	3	35	6	2	0	1	28
3	0	12	51	2	14	14	3	41	23	4	10	49	3	32	50	1	56	5	27
4	0	17	8	2	17	52	3	43	26	4	10	39	3	30	30	1	52	6	26
5	0	21	24	2	21	27	3	45	[illegible]	4	10	24	3	28	[illegible]	1	48	4	25
6	0	25	39	2	25	9	3	47	19	4	10	4	3	25	35	1	44	1	24
7	0	28	55	2	28	[illegible]	3	49	7	4	9	37	3	23	0	1	39	56	23
8	0	31	11	2	31	57	3	50	50	4	9	10	3	20	20	1	35	49	22
9	0	38	25	2	35	22	3	52	29	4	8	37	3	17	3	1	31	41	21
10	0	42	3	2	38	44	3	54	4	4	7	[illegible]	3	14	49	1	27	31	20
11	0	46	52	2	[illegible]	[illegible]	3	55	36	4	7	16	3	11	59	1	23	[illegible]	19
12	0	51	4	2	45	18	3	57	2	4	6	29	3	9	6	1	19	5	18
13	0	55	17	2	48	30	3	58	27	4	5	37	3	6	10	1	14	49	17
14	0	59	27	2	51	40	3	59	49	4	4	41	3	3	10	1	10	37	16
15	1	3	36	2	54	48	4	1	7	4	3	40	3	0	7	1	6	15	15
16	1	7	45	2	57	53	4	2	18	4	2	35	2	57	0	1	1	56	14
17	1	11	53	3	0	54	4	3	22	4	1	26	2	53	49	0	57	36	13
18	1	16	0	3	3	51	4	4	22	4	0	12	2	50	36	0	53	15	12
19	1	20	6	3	6	45	4	5	16	3	58	52	2	47	18	0	48	52	11
20	1	24	10	3	9	36	4	6	10	3	57	27	2	43	57	0	44	23	10
21	1	28	12	3	12	24	4	6	58	3	55	9	2	40	[illegible]	0	[illegible]	2	9
22	1	32	12	3	15	9	4	7	41	3	54	26	2	37	6	0	35	36	8
23	1	36	10	3	17	51	4	8	21	3	52	49	2	33	35	0	31	10	7
24	1	40	6	3	20	30	4	8	57	3	51	9	2	30	2	0	26	44	6
25	1	44	1	3	23	5	4	9	29	3	49	26	2	26	26	0	22	17	5
26	1	47	54	3	25	[illegible]	4	9	55	3	47	38	2	22	47	0	17	50	4
27	1	51	46	3	28	3	4	10	16	3	45	44	2	19	5	0	13	23	3
28	1	55	37	3	30	26	4	10	33	3	43	45	2	15	20	0	8	56	2
29	1	59	26	3	32	45	4	10	45	3	41	40	2	11	35	0	4	29	1
30	2	3	12	3	35	0	4	10	53	3	39	30	2	7	45	0	0	0	0
Deg.	11 Signs.			10 Signs.			9 Signs.			8 Signs.			7 Signs.			6 Signs.			Deg.

Add

TABLE VIII. *Equation of the Moon's mean Anomaly.*

Argument. Sun's mean Anomaly.

Subtract

Deg.	0 Sign.			1 Sign.			2 Signs.			3 Signs.			4 Signs.			5 Signs.			Deg.
	°	′	″	°	′	″	°	′	″	°	′	″	°	′	″	°	′	″	
0	0	0	0	0	46	45	1	21	32	1	35	1	1	23	4	0	48	19	30
1	0	1	37	0	48	10	1	22	21	1	35	2	1	22	14	0	46	51	29
2	0	3	13	0	49	34	1	23	10	1	35	1	1	21	24	0	45	23	28
3	0	4	52	0	50	53	1	23	57	1	35	0	1	20	32	0	43	54	27
4	0	6	28	0	52	19	1	24	41	1	34	57	1	19	38	0	42	24	26
5	0	8	6	0	53	40	1	25	24	1	34	50	1	18	42	0	40	58	25
6	0	9	42	0	55	0	1	26	6	1	34	43	1	17	45	0	39	21	24
7	0	11	20	0	56	21	1	26	48	1	34	33	1	16	46	0	37	49	23
8	0	12	56	0	57	38	1	27	28	1	34	22	1	15	47	0	36	15	22
9	0	14	33	0	58	56	1	28	6	1	34	9	1	14	44	0	34	40	21
10	0	16	10	1	0	13	1	28	43	1	33	53	1	13	41	0	33	5	20
11	0	17	47	1	1	29	1	29	17	1	33	37	1	12	37	0	31	31	19
12	0	19	23	1	2	43	1	29	51	1	33	20	1	11	33	0	29	54	18
13	0	20	59	1	3	56	1	30	22	1	33	0	1	10	26	0	28	18	17
14	0	22	35	1	5	8	1	30	50	1	32	38	1	9	17	0	26	40	16
15	0	24	10	1	6	18	1	31	19	1	32	14	1	8	8	0	25	3	15
16	0	25	45	1	7	27	1	31	45	1	31	50	1	6	58	0	23	23	14
17	0	27	19	1	8	36	1	32	12	1	31	23	1	5	46	0	21	45	13
18	0	28	52	1	9	42	1	32	34	1	30	55	1	4	32	0	20	7	12
19	0	30	25	1	10	49	1	32	57	1	30	25	1	3	19	0	18	28	11
20	0	31	57	1	11	54	1	33	17	1	29	54	1	2	1	0	16	48	10
21	0	33	29	1	12	58	1	33	36	1	29	20	1	0	45	0	15	8	9
22	0	35	2	1	14	1	1	33	52	1	28	45	0	59	26	0	13	28	8
23	0	36	32	1	15	1	1	34	6	1	28	9	0	58	7	0	11	48	7
24	0	38	1	1	16	0	1	34	18	1	27	30	0	56	45	0	10	7	6
25	0	39	29	1	16	59	1	34	30	1	26	50	0	55	23	0	8	20	5
26	0	40	59	1	17	57	1	34	40	1	26	27	0	54	1	0	6	44	4
27	0	42	26	1	18	52	1	34	48	1	25	5	0	52	37	0	5	3	3
28	0	43	54	1	19	47	1	34	54	1	24	39	0	51	12	0	3	21	2
29	0	45	19	1	20	40	1	34	58	1	23	52	0	49	45	0	1	40	1
30	0	47	45	1	21	32	1	35	1	1	23	4	0	48	19	0	0	0	0
Deg.	11 Signs.			10 Signs.			9 Signs.			8 Signs.			7 Signs.			6 Signs.			Deg.

Add

TABLE IX. *The second Equation of the mean to the true Syzygy.*

Argument. Moon's equated Anomaly

Add

Deg.	0 Sign. H. M. S.	1 Sign. H. M. S.	2 Signs. H. M. S	3 Signs. H. M. S	4 Signs. H. M. S.	5 Signs H. M. S.	Deg.
0	0 0 0	5 12 48	8 47 8	9 46 44	8 8 59	4 34 33	30
1	0 10 58	5 21 56	8 51 45	9 45 [illegible]	8 3 12	4 26 [illegible]	29
2	0 21 56	5 30 57	8 56 10	9 45 12	7 57 27	4 17 25	28
3	0 32 54	5 39 51	9 0 25	9 44 11	7 51 53	4 8 47	27
4	0 42 52	5 48 37	9 4 31	9 42 54	7 45 46	4 0 7	26
5	0 54 50	5 57 17	9 8 25	9 41 36	7 39 46	3 1 25	25
6	1 5 48	6 5 51	9 12 9	9 40 [illegible]	7 33 30	3 42 22	24
7	1 16 46	6 14 19	9 15 43	9 38 19	7 27 22	3 33 [illegible]	23
8	1 27 44	6 22 41	9 19 5	9 36 24	7 21 2	3 24 42	22
9	1 38 40	6 30 57	9 22 14	9 34 18	7 14 30	3 15 43	21
10	1 49 33	6 39 4	9 25 12	9 32 1	7 7 50	3 6 43	20
11	2 0 23	6 47 0	9 27 58	9 29 33	7 1 [illegible]	2 57 [illegible]	19
12	2 11 10	6 54 46	9 30 3[illegible]	9 26 54	6 54 8	2 48 39	18
13	2 21 54	7 3 24	9 32 58	9 24 4	6 47 [illegible]	2 39 34	17
14	2 32 34	7 9 52	9 35 12	9 21 [illegible]	6 40 6	2 30 28	16
15	2 43 9	7 17 9	9 37 14	9 17 51	6 32 56	2 21 19	15
16	2 53 38	7 24 10	9 39 8	9 14 28	6 25 40	2 12 8	14
17	3 4 3	7 31 18	9 40 51	9 10 54	6 18 18	2 2 53	13
18	3 14 24	7 38 9	9 42 21	9 7 9	6 10 4[illegible]	1 53 36	12
19	3 24 42	7 44 51	9 43 42	9 3 15	6 3 16	1 44 16	11
20	3 34 58	7 51 24	9 44 53	8 59 6	5 55 38	1 34 54	10
21	3 45 11	7 57 45	9 45 52	8 54 5[illegible]	5 47 54	1 25 3[illegible]	9
22	3 55 21	8 3 56	9 46 38	8 50 24	5 40 4	1 16 7	[illegible]
23	4 5 26	8 9 57	9 47 13	8 45 48	5 32 9	1 6 41	7
24	4 25 26	8 15 46	9 47 36	8 41 [illegible]	5 24 9	0 57 13	6
25	4 25 20	8 21 24	9 47 49	8 36 6	5 16 5	0 47 44	5
26	4 35 6	8 26 53	9 47 54	8 31 [illegible]	5 7 56	0 38 13	4
27	4 44 42	8 32 11	9 47 46	8 25 44	4 59 42	0 28 41	3
28	4 54 11	8 37 19	9 47 33	8 20 18	4 51 15	0 19 8	2
29	5 3 33	8 42 18	9 47 14	8 14 35	4 43 2	0 9 34	1
30	5 12 46	8 47 8	9 46 44	8 8 59	4 34 33	0 0 0	0
Deg.	11 Signs.	10 Signs	[illegible] Signs	8 Signs	7 Signs.	6 Signs.	Deg.

Subtract

TABLE X. *The third Equation of the mean to the true Syzygy.*

Argument. Sun's Anomaly. Moon's Anomaly.

Degrees	Signs. 0 Sub 6 Add M.	S.	Signs. 1 Sub 7 Add M.	S.	Signs. 2 Sub 8 Add M.	S.	Degrees
0	0	0	2	22	4	12	30
1	0	5	2	26	4	15	29
2	0	10	2	30	4	18	28
3	0	15	2	34	4	21	27
4	0	20	2	38	4	24	26
5	0	25	2	42	4	27	25
6	0	30	2	46	4	30	24
7	0	35	2	50	4	32	23
8	0	40	2	54	4	34	22
9	0	45	2	58	4	36	21
10	0	50	3	2	4	38	20
11	0	55	3	6	4	40	19
12	1	0	3	10	4	42	18
13	1	5	3	14	4	44	17
14	1	10	3	18	4	46	16
15	1	15	3	22	4	48	15
16	1	20	3	26	4	50	14
17	1	25	3	30	4	51	13
18	1	30	3	34	4	52	12
19	1	35	3	38	4	53	11
20	1	40	3	42	4	54	10
21	1	45	3	45	4	55	9
22	1	49	3	48	4	56	8
23	1	52	3	51	4	57	7
24	1	56	3	54	4	57	6
25	2	0	3	57	4	57	5
26	2	4	4	0	4	58	4
27	2	9	4	3	4	58	3
28	2	13	4	6	4	58	2
29	2	18	4	9	4	58	1
30	2	22	4	12	4	58	0
Degrees	Signs. 5 Sub. 11 Add		Signs. 4 Sub. 10 Add		Signs. 3 Sub. 9 Add		Degrees

TABLE XI. *The fourth Equation of the mean to the true Syzygy.*

Argument. Sun's mean Distance from the Node.

Add

Deg.	0, 6 Sig. M.	S.	1, 7 Sig. M.	S.	2, 8 Sig. M.	S.	Deg.
0	0	0	1	22	1	22	30
1	0	4	1	23	1	21	29
2	0	7	1	24	1	20	28
3	0	10	1	25	1	18	27
4	0	13	1	26	1	16	26
5	0	16	1	27	1	14	25
6	0	20	1	28	1	12	24
7	0	23	1	29	1	10	23
8	0	26	1	30	1	8	22
9	0	29	1	31	1	6	21
10	0	32	1	32	1	3	20
11	0	35	1	33	1	0	[illegible]
12	0	38	1	33	0	57	18
13	0	41	1	34	0	54	17
14	0	44	1	34	0	51	16
15	0	47	1	34	0	49	16
16	0	50	1	34	0	45	14
17	0	52	1	34	0	41	13
18	0	54	1	34	0	37	12
19	0	57	1	33	0	34	11
20	1	0	1	33	0	31	10
21	1	2	1	32	0	28	9
22	1	5	1	31	0	25	8
23	1	8	1	30	0	22	7
24	1	10	1	29	0	19	6
25	1	12	1	28	0	16	5
26	1	14	1	27	0	13	4
27	1	16	1	26	0	10	3
28	1	18	1	25	0	6	2
29	1	20	1	24	0	3	1
30	1	22	1	22	0	0	0
Degrees	5, 11 Sig.		4, 10 Sig.		3, 9 Sig.		Degrees

Subtract.

TABLE XII. *The Sun's mean Longtiude, Motion, and Anomaly; Old Style.*

Years beginning	Sun's mean Longitude.				Sun's mean Anomaly.		
	s	°	′	″	s	°	′
1	9	7	53	10	6	28	48
201	9	9	23	50	6	26	57
301	9	10	9	10	6	26	1
401	9	10	54	30	6	25	5
501	9	11	39	50	6	24	9
1001	9	15	26	30	6	19	32
1101	9	16	11	50	6	18	36
1201	9	16	57	10	6	17	40
1301	9	17	42	30	6	16	44
1401	9	18	27	50	6	15	49
1501	9	19	13	10	6	14	53
1601	9	19	58	30	6	13	57
170.	9	20	43	50	6	13	1
1801	9	21	29	10	6	12	6

Years complete	Sun's mean Motion.				Sun's mean Anomaly.		
	s	°	′	″	s	°	′
1	11	29	45	40	11	29	45
2	11	29	31	20	11	29	29
3	11	29	17	0	11	29	14
4	0	0	1	49	11	29	58
5	11	29	47	29	11	29	42
6	11	29	33	9	11	29	27
7	11	29	18	49	11	29	11
8	0	0	3	38	11	29	5
9	11	29	49	18	11	29	40
10	11	29	34	58	11	29	24
11	11	29	20	38	11	29	9
12	0	0	5	26	11	29	53
13	11	29	51	7	11	29	37
14	11	29	36	47	11	29	22
15	11	29	22	27	11	29	7
16	0	0	7	15	11	29	50
17	11	29	52	55	11	29	35
18	11	29	38	35	11	29	20

Years complete	Sun's mean Motion.				Sun's mean Anomaly.		
	s	°	′	″	s	°	′
19	11	29	24	16	11	29	4
20	0	0	9	4	11	29	48
40	0	0	18	8	11	29	37
60	0	0	27	12	11	29	26
80	0	0	36	16	11	29	15
100	0	0	45	20	11	29	4
200	0	1	20	40	11	28	8
300	0	2	16	0	11	27	12
400	0	3	1	20	11	26	16
500	0	3	46	40	11	25	21
600	0	4	32	0	11	24	25
700	0	5	17	20	11	23	29
800	0	6	2	40	11	22	33
900	0	6	48	0	11	21	37
1000	0	7	33	20	11	20	11
2000	0	15	6	40	11	11	22
3000	0	22	40	0	11	2	3
4000	1	0	13	20	10	22	44
5000	1	7	46	40	10	13	25
6000	1	15	20	0	10	4	6

Months.	Sun's mean Motion.				Sun's mean Anomaly.		
	s	°	′	″	s	°	′
Jan.	0	0	0	0	0	0	0
Feb.	1	0	33	18	1	0	33
Mar	1	28	9	11	1	28	9
Apr.	2	28	42	30	2	28	42
May	3	28	16	40	3	28	17
June	4	28	49	58	4	28	50
July	5	28	24	8	5	28	34
Aug.	6	29	57	26	6	38	57
Sept.	7	29	30	44	7	29	30
Oct.	8	29	4	54	8	29	4
Nov.	9	29	38	12	9	29	37
Dec.	10	29	12	22	10	29	11

TABLE XII. *concluded.*

Days.	Sun's mean Motion and Anomaly.				Sun's mean Motion and Anomaly.				Sun's mean Dist. from Node.			Sun's mean Motion and Anomaly.				Sun's mean Dist. from Node.		
	s	°	′	″	H M S	° ′ ″	′ ″ ‴	″ ‴ ⁗	° ′ ″	′ ″ ‴	″ ‴ ⁗	H M S	° ′ ″	′ ″ ‴	″ ‴ ⁗	° ′ ″	′ ″ ‴	″ ‴ ⁗
1	0	0	59	8	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2	0	1	58	17	1	0	2	28	0	2	36	31	1	16	23	1	20	30
3	0	2	57	25	2	0	4	56	0	5	12	32	1	18	51	1	23	6
4	0	3	56	33	3	0	7	24	0	7	48	33	1	21	19	1	25	42
5	0	4	55	42	4	0	9	51	0	10	23	34	1	23	47	1	28	18
6	0	5	54	50	5	0	12	19	0	12	50	35	1	26	15	1	30	54
7	0	6	53	58	6	0	14	47	0	15	35	36	1	28	42	1	33	29
8	0	7	53	7	7	0	17	15	0	18	11	37	1	31	10	1	36	5
9	0	8	52	15	8	0	19	43	0	20	47	38	1	33	38	1	38	40
10	0	9	51	23	9	0	22	11	0	23	23	39	1	36	6	1	41	16
11	0	10	50	32	10	0	24	38	0	25	58	40	1	38	34	1	43	52
12	0	11	49	40	11	0	27	6	0	28	34	41	1	41	2	1	46	28
13	0	12	48	48	12	0	29	34	0	31	10	42	1	43	30	1	49	4
14	0	13	47	57	13	0	32	2	0	33	45	43	1	45	57	1	51	39
15	0	14	47	5	14	0	34	36	0	36	21	44	1	48	25	1	54	15
16	0	15	46	13	15	0	36	58	0	38	57	45	1	50	53	1	55	51
17	0	16	45	22	16	0	39	26	0	41	33	46	1	53	21	1	59	27
18	0	17	44	30	17	0	41	53	0	44	8	47	1	55	49	2	2	3
19	0	18	43	38	18	0	44	21	0	46	44	48	1	58	17	2	4	39
20	0	19	42	47	19	0	46	49	0	49	20	49	2	0	44	2	7	13
21	0	20	41	55	20	0	49	17	0	51	56	50	2	3	12	2	9	50
22	0	21	41	3	21	0	51	45	0	54	32	51	2	5	40	2	12	25
23	0	22	40	12	22	0	54	13	0	57	8	52	2	8	8	2	15	2
24	0	23	39	20	23	0	56	40	0	59	43	53	2	10	36	2	17	38
25	0	24	38	28	24	0	59	8	1	2	19	54	2	13	4	2	20	14
26	0	25	37	37	25	1	1	36	1	4	55	55	2	15	32	2	22	50
27	0	26	36	45	26	1	4	4	1	7	31	56	2	17	59	2	25	26
28	0	27	35	53	27	1	6	32	1	10	7	57	2	20	27	2	28	8
29	0	28	35	2	28	1	9	0	1	12	43	58	2	22	55	2	30	32
30	0	29	34	10	29	1	11	28	1	15	19	59	2	25	23	2	33	14
31	1	30	33	18	30	1	13	55	1	17	55	60	2	27	51	2	35	50

In leap-years, after *February*, add one day, and one day's motion.

TABLE XIII. *Equation of the Sun's Centre, or the Difference between his mean and true Place.*

Argument, Sun's mean Anomaly.

Subtract.

Degrees	0 Sign.			1 Sign.			2 Signs.			3 Signs			4 Signs.			5 Signs.			Degrees
	°	′	″	°	′	″	°	′	″	°	′	″	°	′	″	°	′	″	
0	0	0	0	0	56	47	1	39	6	1	55	37	1	41	12	0	58	53	30
1	0	1	59	0	58	30	1	40	7	1	55	39	1	40	12	0	57	7	29
2	0	3	57	1	0	12	1	41	6	1	55	38	1	39	10	0	55	19	28
3	0	5	56	1	1	53	1	42	3	1	55	36	1	38	6	0	53	30	27
4	0	7	54	1	3	33	1	42	59	1	55	31	1	37	0	0	51	40	26
5	0	9	52	1	5	12	1	43	52	1	55	24	1	35	52	0	49	49	25
6	0	11	50	1	6	50	1	44	44	1	55	15	1	34	43	0	47	57	24
7	0	13	48	1	8	27	1	45	34	1	55	3	1	33	32	0	46	5	23
8	0	15	46	1	10	2	1	46	22	1	54	50	1	32	19	0	44	11	22
9	0	17	43	1	11	36	1	47	8	1	54	35	1	31	4	0	42	16	21
10	0	19	40	1	13	9	1	47	53	1	54	17	1	29	47	0	40	21	20
11	0	21	37	1	14	41	1	48	35	1	53	57	1	28	29	0	38	25	19
12	0	23	33	1	16	11	1	49	15	1	53	36	1	27	9	0	36	28	18
13	0	25	29	1	17	40	1	49	54	1	53	12	1	25	48	0	34	30	17
14	0	27	25	1	19	8	1	50	30	1	52	46	1	24	25	0	32	32	16
15	0	29	20	1	20	34	1	51	5	1	52	18	1	23	0	0	30	33	15
16	0	31	15	1	21	59	1	51	37	1	51	48	1	21	34	0	28	33	14
17	0	33	9	1	23	22	1	52	8	1	51	17	1	20	6	0	26	33	13
18	0	35	2	1	24	44	1	52	36	1	50	41	1	18	36	0	24	33	12
19	0	36	55	1	26	5	1	53	8	1	50	3	1	17	5	0	22	32	11
20	0	38	47	1	27	24	1	53	27	1	49	26	1	15	33	0	20	30	10
21	0	40	38	1	28	41	1	53	50	1	48	46	1	13	59	0	18	28	9
22	0	42	30	1	29	57	1	54	10	1	48	3	1	12	24	0	16	26	8
23	0	44	20	1	31	11	1	54	28	1	47	19	1	10	47	0	14	24	7
24	0	46	9	1	32	25	1	54	44	1	46	32	1	9	9	0	12	21	6
25	0	47	57	1	33	35	1	54	58	1	45	44	1	7	29	0	10	18	5
26	0	49	45	1	34	45	1	55	10	1	44	53	1	5	49	0	8	14	4
27	0	51	32	1	35	53	1	55	20	1	44	1	1	4	7	0	6	11	3
28	0	53	18	1	36	59	1	55	28	1	43	7	1	2	24	0	4	7	2
29	0	55	3	1	38	3	1	55	34	1	42	10	1	0	39	0	2	4	1
30	0	56	47	1	39	6	1	55	37	1	41	12	0	58	53	0	0	0	0
Deg.	11 Signs			10 Signs.			9 Signs.			8 Signs.			7 Signs.			6 Signs.			Deg.

Add.

TABLE XIV. *The Sun's Declination.*

Argument, Sun's true Place

Degrees.	Signs. 0 N. 6 S. ° '	Signs. 1 N. 7 S. ° '	Signs. 2 N. 8 S. ° '	Degrees.
0	0 0	11 30	20 11	30
1	0 24	11 51	20 24	29
2	0 48	12 11	20 36	28
3	1 12	12 32	20 48	27
4	1 36	12 53	20 59	26
5	1 59	13 13	21 10	25
6	2 23	13 33	21 21	24
7	2 47	13 53	21 31	23
8	3 11	14 12	21 41	22
9	3 34	14 31	21 50	21
10	3 58	14 50	21 59	20
11	4 22	15 9	22 8	19
12	4 45	15 28	22 16	18
13	5 9	15 46	22 24	17
14	5 32	16 4	22 31	16
15	5 35	16 22	22 38	15
16	6 18	16 39	22 45	14
17	6 41	16 57	22 51	13
18	7 4	17 14	22 56	12
19	7 27	17 30	23 2	11
20	7 50	17 46	23 6	10
21	8 15	18 2	23 11	9
22	8 35	18 18	23 14	8
23	9 57	18 33	23 18	7
24	9 20	18 48	23 21	6
25	9 42	19 3	23 21	5
26	10 4	19 17	23 25	4
27	10 25	19 31	23 27	3
28	10 47	19 45	23 28	2
29	11 8	19 58	23 29	1
30	11 30	20 11	23 29	0
Degrees	Signs. 11 S. 5 N.	Signs. 10 S. 4 N.	Signs. 9 S. 3 N.	Degrees

TABLE XV. *Equation of the Sun's mean Distance from the Node.*

Argument, Sun's mean Anomaly.

Subtract.

Deg.	0 Sig ° '	1 Sig ° '	2 Sig ° '	3 Sig. ° '	4 Sig ° '	5 Si. ° '	Deg.
0	0 0	1 2	1 47	2 5	1 50	1 4	30
1	0 2	1 4	1 48	2 5	1 48	1 2	29
2	0 4	1 6	1 49	2 5	1 47	1 0	28
3	0 6	1 8	1 50	2 5	1 46	0 58	27
4	0 9	1 10	1 51	2 5	1 45	0 56	26
5	0 11	1 12	1 52	2 5	1 44	0 54	25
6	0 13	1 14	1 53	2 5	1 43	0 52	24
7	0 15	1 16	1 54	2 4	1 41	0 50	23
8	0 17	1 17	1 55	2 4	1 40	0 48	22
9	0 19	1 18	1 56	2 4	1 39	0 46	21
10	0 21	1 19	1 57	2 4	1 37	0 44	20
11	0 23	1 21	1 58	2 3	1 36	0 42	19
12	0 25	1 22	1 58	2 3	1 34	0 40	18
13	0 28	1 24	1 59	2 3	1 33	0 37	17
14	0 30	1 26	2 0	2 2	1 31	0 35	16
15	0 32	1 27	2 0	2 2	1 30	0 33	15
16	0 34	1 28	2 1	2 1	1 28	0 31	14
17	0 36	1 30	2 1	2 1	1 27	0 29	13
18	0 38	1 31	2 2	2 0	1 25	0 27	12
19	0 40	1 34	2 2	2 0	1 24	0 24	11
20	0 42	1 35	2 3	1 59	1 23	0 22	10
21	0 44	1 36	2 3	1 59	1 21	0 20	9
22	0 46	1 37	2 4	1 58	1 19	0 18	8
23	0 48	1 39	2 4	1 57	1 17	0 16	7
24	0 50	1 40	2 4	1 56	1 15	0 13	6
25	0 52	1 41	2 4	1 [illegible]	1 1	0 11	5
26	0 54	1 43	2 5	1 54	1 11	0 9	4
27	0 56	1 44	2 5	1 53	1 9	0 7	3
28	0 58	1 45	2 5	1 52	1 8	0 5	2
29	1 0	1 46	2 5	1 51	1 6	0 3	1
30	1 2	1 47	2 5	1 60	1 4	0 0	0
Deg.	11 Sig	10 Sig.	9 Sig.	8 Sig.	7 Sig.	6 Sig.	Deg.

Add.

TABLE XVI.

The Moon's Latitude in Eclipses.

Argument, Moon's equated Distance from the Node.

0 Sign *North Ascending.* 6 Signs *South Descending.*				
0	0	′	″	0
0	0	0	0	30
1	0	5	15	29
2	0	10	30	28
3	0	15	45	27
4	0	20	59	26
5	0	26	13	25
6	0	31	26	24
7	0	36	39	23
8	0	41	51	22
9	0	47	22	21
10	0	52	13	20
11	0	57	23	19
12	1	2	31	18
13	1	7	38	17
14	1	12	44	16
15	1	17	49	15
16	1	22	52	14
17	1	27	53	13
18	1	32	52	12
19	1	37	49	11
				5 Signs *North Descending.* 11 Signs *South Ascending.*

This Table shews the Moon's Latitude a little beyond the utmost Limits of Eclipses.

TABLE XVII.

The Moon's horizontal Parallax, with the Semidiameters and true Horary Motion of the Sun and Moon, and every sixth Degree of their mean Anomalies, the Quantities for the intermediate Degrees being easily proportioned by Sight.

Anomaly of Sun and Moon.		Moon's horizont. Parallax.		Sun's Semidiameter.		Moon's Semidiameter.		Moon's Horary Motion.		Sun's Horary Motion.		Anomaly of Sun and Moon.	
s	°	′	″	′	″	′	″	′	″	′	″	s	°
0	0	54	29	15	50	14	54	30	10	2	23	12	0
	6	54	31	15	50	14	55	30	12	2	23		24
	12	54	34	15	50	14	56	30	15	2	23		18
	18	54	40	15	51	14	57	30	19	2	23		12
	24	54	47	15	51	14	58	30	26	2	23		6
1	0	54	56	15	52	14	59	30	34	2	24	11	0
	6	55	6	15	53	15	1	30	44	2	24		24
	12	55	17	15	54	15	4	30	55	2	24		18
	18	55	29	15	55	15	8	31	9	2	24		12
	24	55	42	15	56	15	12	31	23	2	25		6
2	0	55	56	15	58	15	17	31	40	2	25	10	0
	6	56	12	15	59	15	22	31	56	2	26		24
	12	56	29	16	1	15	26	32	17	2	27		18
	18	56	48	16	2	15	30	32	39	2	27		12
	24	57	8	16	4	15	36	33	11	2	28		6
3	0	57	30	16	6	15	41	33	23	2	28	9	0
	6	57	52	16	8	15	46	33	47	2	29		24
	12	58	12	16	10	15	51	34	11	2	29		18
	18	58	31	16	11	15	58	34	34	2	29		12
	24	58	49	16	13	16	3	34	58	2	30		6
4	0	59	6	16	14	16	9	35	22	2	30	8	0
	6	59	21	16	15	16	14	35	45	2	31		24
	12	59	35	16	17	16	19	36	0	2	31		18
	18	59	48	16	19	16	24	36	20	2	32		12
	24	60	0	16	20	16	28	36	40	2	32		6
5	0	60	11	16	21	16	31	37	0	2	32	7	0
	6	60	21	16	21	16	32	37	10	2	33		24
	12	60	30	16	22	16	37	37	19	2	33		18
	18	60	38	16	22	16	38	37	28	2	33		12
	24	60	45	16	23	16	39	37	36	2	33		6
6	0	60	45	16	23	16	39	37	40	2	33	6	0

To calculate the true Time of New or Full Moon.

PRECEPT I. If the required time be within the limits of the 18th century, write out the mean time of new Moon in *March*, for the proposed year, from Table I, in the old style, or from Table II, in the new; together with the mean anomalies of the Sun and Moon, and the Sun's mean distance from the Moon's ascending node.—If you want the time of full Moon in *March*, add the half lunation at the foot of Table III, with its anomalies, &c. to the former numbers, if the new Moon fall before the 15th of *March;* but if it fall after, subtract the half lunation, with the anomalies, &c. belonging to it, from the former numbers, and write down the respective sums or remainders.

II. In these additions or subtractions, observe, that 60 seconds make a minute, 60 minutes make a degree, 30 degrees make a sign, and 12 signs make a circle. When you exceed 12 signs in addition, reject 12, and set down the remainder.—When the number of signs to be subtracted is greater than the number you subtract from, add 12 signs to the lesser number, and then you will have a remainder to set down.—In the tables, signs are marked thus ^{s}, degrees thus $^\circ$, minutes thus $'$, and seconds thus $''$.

III. When the required new or full Moon is in any given month after *March*, write out as many lunations, with their anomalies, and the Sun's distance from the node, from Table III. as the given month is after *March;* setting them in order below the numbers taken out for *March*.

IV. Add all these together, and they will give the mean time of the required new or full Moon, with the mean anomalies and Sun's mean distance from the ascending node, which are the argume for finding the proper equations.

V. With the number of days added together, enter Table IV, under the given month and against that number you have the day of mean new or full Moon in the left-hand column, which set before the hours, minutes, and seconds, already found.

But (as it will sometimes happen) if the said number of days fall short of any in the column under the given month, add one lunation and its anomalies, &c. (from Table III, to the foresaid sums, and then you will have a new sum of days wherewith to enter Table IV, under the given month, where you are sure to find it the second time if the first fall short.

VI. With the signs and degrees of the Sun's anomaly, enter Table VII, and therewith take out the annual or first equation for reducing the mean syzygy to the true; taking care to make proportions in the table for the odd minutes and seconds of anomaly, as the table gives the equation only to whole degrees.

Observe in this and every other case of finding equations, that if the signs be at the head of the table, their degrees are at the left hand, and are reckoned downward; but if the signs be at the foot of the table, their degrees are at the right hand, and are counted upward; the equation being in the body of the table, under or over the signs, in a collateral line with the degrees.—The titles *Add* or *Subtract* at the head or foot of the tables where the signs are found, shew whether the equation is to be added to the mean time of new or full Moon, or to be subtracted from it. In this table, the equation is to be subtracted if the signs of the Suns anomaly be found at the head of the table; but it is to be added, if the signs be at the foot.

VII. With the signs and degrees of the Sun's mean anomaly, enter Table VIII, and take out

the equation of the Moon's mean anomaly; subtract this equation from her mean anomaly, if the signs of the Sun's anomaly be at the head of the table, but add it if they be at the foot; the result will be the Moon's equated anomaly, with which enter Table IX, and take out the second equation for reducing the mean to the true time of new or full Moon; adding this equation, if the signs of the Moon's anomaly be at the head of the table, but subtracting it if they be at the foot, and the result will give you the mean time of the required new or full Moon twice equated, which will be sufficiently near for common almanacks.—But when you want to calculate an eclipse, the following equations must be used: thus,

VIII. Subtract the Moon's equated anomaly from the Sun's mean anomaly, and with the remainder in signs and degrees, enter Table X, and take out the third equation, applying it to the former equated time, as the titles *Add* or *Subtract* do direct.

IX. With the Sun's mean distance from the ascending node enter Table XI, and take out the equation answering to that argument, adding it to, or subtracting it from, the former equated time, as the titles direct, and the result will give the time of new or full Moon, agreeing with well-regulated clocks or watches, very near the truth. But, to make it agree with the solar, or apparent time, apply the equation of natural days, found in the table (from page 193 to page 205) as it is leap-year, or the first, second, or third after.

The method of calculating the time of any new or full Moon without the limits of the 18th century, will be shewn further on. And a few examples, compared with the precepts, will make the whole work plain.

N. B. The tables begin the day at noon, and reckon forward from thence to the noon following. —Thus, *March* the 31st, at 22h. 30min. 25sec. of tabular time, is *April* 1st (in common reckoning) at 30min. 25sec. after 10 o'clock in the morning.

EXAMPLE I.

Required the true Time of New Moon in April 1764, *New Style.*

By the Precepts,	New Moon.				Sun's Anom.				Moon's Anom.				Sun fro. Node.			
	D.	H.	M.	S.	s	°	′	″	s	°	′	″	s	°	′	″
March 1764,	2	8	55	36	8	2	20	0	10	13	35	21	11	4	54	48
Add 1 lunation,	29	12	44	3	0	29	6	19	0	25	49	0	1	0	40	14
Mean new Moon,	31	2[illegible]	39	39	9	1	26	19	11	9	24	21	0	5	35	2
First equation,	+	4	10	40	11	10	59	18	+	1	34	57	Sun fro. Node,			
Time once equated,	32	1	50	19	9	20	27	1	11	10	59	18	and Arg. fourth			
Second equation,	—	3	24	49	Arg. 3d equat.				Arg. 2d equat.				equation.			
Time twice equated,	31	22	25	30												
Third equation,		+	4	37												
Time thrice equated,	31	22	30	7												
Fourth equation,			+	18												
True new Moon,	31	22	30	25												
Equation of days,		—	3	48												
Apparent time,	31	22	26	37												

So the mean time is 22 h. 30 m. 25 sec. after the noon of the 31st *March;* that is, *April* 1st, at 30 min. 25 sec. after X in the morning. But the apparent time is 26 min. 37 sec. after X in the morning.

EXAMPLE II.

Qu. *The true mean time of Full Moon in May, 1762, Old Style.*

By the Precepts.	New Moon.	Sun's Anom.	Moon's Anom.	Sun fro. Node.
	D. H. M. S.	s ° ′ ″	s ° ′ ″	s ° ′ ″
March 1762,	24 15 18 24	8 23 48 16	1 23 59 11	10 18 49 14
Add 2 lunations,	59 1 28 6	1 28 12 39	1 21 38 1	2 1 20 48
New Moon, *May*,	22 16 46 30	10 22 0 55	3 15 37 12	6 20 9 42
Sub. ½ lunation,	14 18 22 2	0 14 33 10	6 12 54 30	0 15 20 7
Full Moon, *May*,	7 22 24 28	10 7 27 45	9 2 42 42	0 4 49 35
First equation,	+ 3 16 36	9 3 57 13	+ 1 14 33	Sun fro. Node, and Arg. 4th equation.
Time once equat.	8 1 41 4	1 3 30 50	9 3 57 15	
Second equation,	— 9 47 53	Arg. 3d equat.	Arg. 2d. equat.	
Time twice equat.	7 15 53 11			
Third equation,	— 2 36			
Time thrice equat.	7 15 50 35			
Fourth equation.	+ 15			
The full Moon,	7 15 50 50			

Ans. *May* 7th at 15 h. 50 m. 50 sec. past noon, viz. *May* 8th at III h. 50 min. 50 sec. in the morning.

To calculate the Time of New and Full Moon in a given Year and Month of any particular Century, between the Christian Æra and the 18th Century.

Precept I. Find a year of the same number in the 18th century with that of the year in the century proposed, and take out the mean time of new Moon in *March*, old style, for that year, with the mean anomalies and Sun's mean distance from the node at that time, as already taught.

II. Take as many complete centuries of years from Table VI. as, when subtracted from the abovesaid year in the 18th century, will answer to the given year; and take out the first mean new Moon and its anomalies, &c. belonging to the said centuries, and set them

below those taken out for *March* in the 18th century.

III. Subtract the numbers belonging to these centuries, from those of the 18th century, and the remainders will be the mean time and anomalies, &c. of new Moon in *March*, in the given year of the century proposed.—Then, work in all respects for the true time of new or full Moon, as shewn in the above precepts and examples.

IV. If the days annexed to these centuries exceed the number of days from the beginning of *March* taken out in the 18th century, add a lunation and its anomalies &c. from Table, III to the time and anomalies of new Moon, in *March*, and then proceed in all respects as above.—This circumstance happens in example V.

EXAMPLE III.

Required the true mean time of Full Moon in April, *Old Style, A. D* 30.

From 1730 subtract 1700 (or 17 centuries) and there remains 30

By the Precepts.	New Moon.	Sun's Anom.	Moon's Anom.	Sun fro. Node.
	D. H. M. S.	s ° ′ ″	s ° ′ ″	s ° ′ ″
March 1730,	7 12 54 16	8 18 4 31	9 0 32 17	1 23 17 16
Add ½ lunation,	14 18 22 2	0 14 33 10	6 12 54 30	0 15 20 7
Full Moon,	22 6 56 18	9 2 37 41	3 13 26 47	2 8 37 23
1700 years subtract,	14 17 36 42	11 28 46 0	10 29 36 6	4 29 23 0
Full ☽ *March, A. D.* 30	7 13 19 36	9 3 51 41	4 13 50 41	9 9 14 23
Add 1 lunation,	29 12 44	0 29 6 19	0 25 49 0	1 0 40 14
Full Moon, *April*,	6 2 3 39	10 2 58 0	5 9 39 47	10 9 34 37
First equation,	+ 3 28 4	5 10 58 40	+ 1 18 53	Sun fro. Node,
Time once equat.	6 5 31 43	4 21 59 20	5 10 58 40	and Arg. 4th
Second equation,	+ 2 57 53	Arg. 3d equat.	Arg. 2d equat.	equation.
Time twice equat.	6 8 29 36			
Third equation,	— 2 54			
Time thrice equated,	6 8 26 44			
Fourth equation,	— 1 33			
True full Moon, *April*,	6 8 25 11			

Hence it appears, that the mean time of full Moon in *April A. D* 30, old style, was on the 6th day, at 25 m. 11 sec. past VIII in the evening.

To calculate the true Time of New or Full Moon in any given Year and Month before the Christian Æra.

PRECEPT I. Find a year in the 18th century, which being added to the given number of years before Christ, diminished by one, shall make a number of complete centuries.

II. Find this number of centuries in Table VI, and subtract the time and anomalies belonging to it from those of the mean new Moon in *March*, the above-found year of the 18th century; and the remainder will denote the time and anomalies, &c. of the mean new Moon in *March*, the given year before Christ. Then, for the true time of that new Moon, in any month of that year, proceed in the manner taught above.

EXAMPLE IV.

Required the mean time of New Moon in May, Old Style, the year before Christ 585.

The years 584 added to 1716, make 2300, or 23 centuries.

By the Precepts.	New Moon. D. H. M. S.	Sun's Anom. s ° ′ ″	Moon's Anom. s ° ′ ″	Sun fro. Node. s ° ′ ″
March 1716,	11 17 33 29	8 22 50 39	4 4 14 2	4 27 17 5
2300 years subtract,	11 5 57 53	11 19 47 0	1 5 59 0	7 25 27 0
Mar. before Christ, 585,	0 11 35 36	9 3 3 39	2 28 15 2	9 1 50 5
Add 3 lunations,	88 14 12 9	2 27 18 58	2 17 27 1	3 2 0 42
May before Christ, 585,	28 1 47 45	0 0 22 37	5 15 42 3	0 3 50 47
First equation,	— 1 37	5 15 41 27	— 36	Sun fro. Node,
Time once equated,	28 1 46 8	6 14 41 10	5 15 41 27	and Arg. 4th
Second equation,	+ 2 14 58	Arg. 3d equat.	Arg. 2d equat	equation.
Time twice equated,	28 4 1 6			
Third equation,	+ 1 13			
Time thrice equated,	28 4 2 19			
Fourth equation,	+ 12			
True new Moon,	28 4 2 31			

So the mean time was *May* 28th, at 2 minutes 31 seconds past IV in the afternoon.

These tables are calculated for the meridian of *London*; but they will serve for any other place, by subtracting four minutes from the tabular time, for every degree that the meridian of the given place is westward of *London*, or adding four minutes for every degree that the meridian of the given place is eastward: as in

EXAMPLE V.

Required the true mean time of Full Moon at Alexandria *in* Egypt, *long.* 30° 21′, 45″ *E. in* September, *Old Style, the year before Christ* 201.

The years 200 added to 1800, make 2000, or 20 centuries.

By the Precepts.	New Moon.				Sun's Anom.				Moon's Anom.				Sun fro. Node.			
	D.	H.	M.	S.	s	°	′	″	s	°	′	″	s	°	′	″
March 1800,	13	0	22	17	8	23	19	55	10	7	52	36	11	3	58	24
Add 1 lunation,	29	12	41	3	0	29	6	1[illegible]	0	25	49	0	1	0	40	14
From the sum	42	13	6	20	9	22	26	14	11	3	41	36	0	4	38	38
Subtract 2000 years,	27	18	9	1[illegible]	0	8	50	0	0	15	42	0	6	27	45	0
N. M. before Christ 201,	14	18	57	1	9	13	36	14	10	17	59	56	5	6	53	38
Add { 6 lunations,	177	4	24	18	5	24	37	56	5	4	54	3	6	4	1	24
Add { half lunation,	14	18	22	2	0	14	33	10	6	12	54	30	0	15	20	7
Full Moon, *September*,	22	17	43	21	3	22	47	20	10	5	48	9	11	26	15	9
First equation,	—	3	53	9	10	4	19	52	—	1	28	17	Sun fro. Node,			
Time once equated,	22	13	50	12	5	18	27	28	10	4	19	52	and Arg. 4th			
Second equation,	—	8	23	4	Arg. 3d equat.				Arg. 2d equat.				equation.			
Time twice equated,	22	5	25	8												
Third equation,			—	58												
Time thrice equated,	22	5	24	10												
Fourth equation,			—	12												
True time at *London*,	22	5	23	58												
Add for *Alexandria*,		2	1	27												
True time there.	22	7	25	25												

Thus it appears, that the true mean time of full Moon at *Alexandria*, in *September*, old style, the year before Christ 201, was the 22d day, at 25 min. 25 sec. after VII in the evening.

EXAMPLE VI.

Required the true mean time of Full Moon at Babylon, *long.* 36° 25′ 15″ E. *in* October, *Old Style, the* 4008*th year before the first year of Christ, or* 4007 *before the year of his birth.*

The years 4007 added to 1793, make 5800, or 58 centuries.

By the Precepts.	New Moon. D.	H.	M.	S.	Sun's Anom. s	°	′	″	Moon's Anom s	°	′	″	Sun fro. Node, s	°	′	″
March 1793,	30	9	13	55	9	10	16	11	8	7	37	56	7	6	18	26
Subtract 5800 years.	15	12	38	7	10	21	35	0	6	24	43	0	9	13	1	0
N. M. before Christ 4007,	14	20	35	48	10	18	41	11	1	12	54	58	9	25	17	26
Add { 7 lunations	206	17	8	21	6	23	44	15	6	0	43	3	7	4	41	38
{ half lunation,	14	18	22	2	0	14	33	10	6	12	54	30	0	15	20	7
Full Moon, *October*,	22	8	6	11	5	26	58	36	1	26	32	31	5	13	19	11
First equation,		—	13	[illegible]	1	26	27	[illegible]		—	5	[illegible]	Sun fro. Node,			
Time once equated,	22	7	52	43	4	0	31	10	1	6	27	26	and Arg. 4th			
Second equation,	+	8	29	20	Arg. 3d equat.				Arg. 2d equat.				equation.			
Time twice equated,	22	16	22	3												
Third equation,		—	4	10												
Time thrice equated,	22	16	17	53												
Fourth equation			—	51												
Full Moon at *London*,	22	16	17	2												
Add for *Babylon*,		2	25	41												
True time there,	22	18	42	43												

So that, on the meridian of *London*, the true time was *October* 23d, at 17 min. 2 sec past IV in the morning; but at *Babylon*, the true time was *October* 23d, at 42 min 43 sec past VI in the morning. This is supposed by some to have been the year of the creation.

To calculate the true Time of New or Full Moon, in any given Year and Month after the 18*th Century.*

Precept I. Find a year of the same number in the 18th century with that of the year proposed, and take out the mean time and anomalies &c. of new Moon in *March*, old style, for that year, in Table I.

II. Take so many years from Table VI, as, when added to the above-mentioned year in the 18th century, will answer to the given year in which the new or full Moon is required: and take out the first new Moon, with its anomalies, for these complete centuries.

III. Add all these together, and then work in all respects as shewn above, only remember to subtract a lunation and its anomalies, when the above-mentioned addition carries the new Moon beyond the 31st of *March* ; as in the following example :

EXAMPLE VII.

Required the true mean time of New Moon in July, *Old Style*, A. D. 2180.

Four centuries (or 400 years) added to *A. D.* 1780, make 2180.

By the Precepts,	New Moon.				Sun's Anom.				Moon's Anom.				Sun fro. Node,			
	D	H	M	S	S	°	′	″	S	°	′	″	S	°	′	″
March 1780.	23	23	1	[illegible]	9	4	18	13	1	21	7	47	10	16	21	1
Add 400 years.	17	8	43	2	0	13	24	0	10	1	38	0	6	17	49	0
From the sum	41	7	45	15	9	17	42	13	11	22	35	47	5	6	10	1
Subtract lunation.	29	12	44	2	0	29	6	19	0	25	49	0	1	0	40	14
New ☽ *March* 2180.	11	19	1	10	8	18	35	54	10	26	46	47	4	5	29	47
Add 4 lunations.	118	2	56	12	3	26	25	17	3	13	16	4	4	2	40	56
New ☽ *July* 2180,	7	21	57	2[illegible]	0	15	1	11	2	10	2	49	8	8	10	43
First equation.	—	1	3	41	3	9	38	38		—	24	11	Sun fro. Node, and Arg. 4th equation.			
Time once equated,	7	20	53	4[illegible]	10	5	22	33	2	9	38	38				
Second equation.	+	9	24	6	Arg. 3d equat.				Arg. 2d equat.							
Time twice equated,	8	6	17	49												
Third equation.		+	3	56												
Time thrice equated,	8	6	21	45												
Fourth equation,		+	1	8												
True time, *July*,	8	6	22	53												

True mean time, *July* 8, at 22 minutes 53 seconds past VI in the evening.

In keeping by the old style, we are always sure to be right, by adding or subtracting whole hundreds of years to or from any given year in the 18th century. But in the new style we may be very apt to make mistakes, on account of the leap-years not coming in regularly every fourth year: And therefore, when we go without the

limits of the 18th century, we had best keep to the old style, and at the end of the calculation reduce the time to the new. Thus, in the 22d century, there will be 14 days difference between the styles; and therefore, the true time of new Moon in this last example being reduced to the new style, will be the 22d of *July*, at 22 minutes 53 seconds past VI in the evening.

To calculate the true Place of the Sun for any given Moment of Time.

PRECEPT I. In Table XII, find the next lesser year in number to that in which the Sun's place is sought, and write out his mean longitude and anomaly answering thereto: to which add his mean motion and anomaly for the complete residue of years, months, days, hours, minutes, and seconds, down to the given time, and this will be the Sun's mean place and anomaly at that time, in the old style; provided the said time be in any year after the Christian æra. *See the first following example.*

II. Enter Table XIII with the Sun's mean anomaly, and making proportions for the odd minutes and seconds thereof, take out the equation of the Sun's centre: which, being applied to his mean place, as the title *Add* or *Subtract* directs, will give his true place or longitude from the vernal equinox at the time for which it was required.

III. To calculate the Sun's place for any time in a given year before the Christian æra, take out his mean longitude and anomaly for the first year thereof, and from these numbers, subtract the mean motions and anomalies for the complete hundreds or thousands next above the given year; and to the remainders add those for the residue of years, months, &c. and then work in all respects as above. *See the second example following.*

EXAMPLE I.

Required the Sun's true place, March 20th, *Old Style*, 1764, *at* 22 *hours* 30 *minutes* 25 *seconds past noon.*— *In common reckoning*, March 21*st*, *at* 10 *hours* 30 *minutes* 25 *seconds in the forenoon.*

		Sun's Longitude.				Sun's Anomaly.			
		s	°	′	″	s	°	′	″
To the radical year after Christ . . .	1701	9	20	43	50	6	13	1	0
Add complete years	60	0	0	27	12	11	29	26	0
	3	11	29	17	0	11	29	14	0
	March	1	28	9	11	1	28	9	0
Bissextile, Days . . .	20		20	41	55		20	41	55
Hours . . .	22			54	13			54	13
Minutes . .	30			1	14			1	14
Seconds . .	25				1				1
Sun's mean place at the given time . . .		0	10	14	36	9	1	27	23
Equation of the Sun's centre, add . . .			1	55	31	Mean Anomaly.			
Sun's true place at the same time . . .		0	12	10	7 or	♈	12	10	7

EXAMPLE II.

Required the Sun's true place, October 23d *Old Style, at* 16 *hours* 57 *minutes past noon, in the* 4008th *year before the year of Christ* 1; *which was the* 4007th *before the year of his birth, and the year of the* Julian *period* 706?

By the Precepts.

		Sun's Longitude. S	°	′	″	Sun's Anomaly. S	°	′	″
From the radical numbers after Christ	1	9	7	53	10	6	28	48	0
Subtract those for 5000 complete years		1	7	46	40	10	13	25	0
Remains, for a new radix		8	0	6	30	8	15	23	0
To which add, to bring it to the given time: complete years	900	0	6	48	0	11	21	37	0
	80	0	0	36	16	11	29	15	0
	12	0	0	5	26	11	29	53	0
	October	8	29	4	54	8	29	4	0
	Days 23		22	40	12		22	40	12
	Hours 16			39	26			39	26
	Minutes 57			2	20			2	20
Sun's mean place at the given time		6	0	3	4	5	28	33	58
Equation of the Sun's centre subtract				3	4	Sun's Anomaly.			
Sun's true place at the same time		6	0	0	0 or	♎	0	0	0

So that in the meridian of *London*, the Sun was then just entering the sign ♎ *Libra*, and consequently was upon the point of the autumnal equinox.

If to the above time of the autumnal equinox at *London*, we add 2 hours 25 minutes 4 seconds for the longitude of *Babylon*, we shall have for the time of the same equinox, at that place, *October* 23d, at 19 hours 22 minutes 41 seconds; which, in the common way of reckoning, is *October* 24th, at 22 minutes 41 seconds past VII in the morning.*

And it appears by example VI, that in the same year, the true time of full Moon at *Babylon* was *October* 23d, at 42 minutes 46 seconds after VI in the morning; so that the autumnal equinox was on the day next after the day of full Moon.—The Dominical letter for that year was *G*, and consequently the 24th of *October* was on a *Wednesday*.

* The reason why this calculation makes the autumnal equinox, in the year of the *Julian period* 706, to be two days sooner than the time of the same equinox mentioned in page 183, is, that in *that* page the mean time only is taken into the account, as if there was no equation of the Sun's motion.

The equation at the autumnal equinox then, did not exceed an hour and a quarter, when reduced to time. But, in the year of Christ 1756, (which was 5763 years after,) the equation at the autumnal equinox amounted to 1 day 22 hours 34 minutes, by which quantity the true time fell later than the mean.—So that if we consider the *true* time of this last-mentioned equinox, only as *mean* time, the mean motion of the Sun carried thence back to the autumnal equinox in the year of the *Julian period* 706 will fix it to the 25th of *October* in that year.

To find the Sun's Distance from the Moon's ascending Node, at the Time of any given New or Full Moon; and consequently, to know whether there is an Eclipse at that Time or not.

The Sun's distance from the Moon's ascending node is the argument for finding the Moon's fourth equation in the syzygies, and therefore it is taken into all the foregoing examples in finding the times of these phenomena.—Thus, at the time of mean new Moon in *April* 1764, the Sun's mean distance from the ascending node is $0^s\ 5^\circ\ 35'\ 2''$. *See Example* I. p. 350.

The descending node is opposite to the ascending one, and they are, therefore, just six signs distant from each other.

When the Sun is within 17 degrees of either of the nodes at the time of new Moon, he will be eclipsed at that time: and when he is within 12 degrees of either of the nodes at the time of full Moon, the Moon will be then eclipsed.—Thus we find, that there will be an eclipse of the Sun at the time of new Moon in *April* 1764.

But the true time of that new Moon comes out by the equations to be 50 minutes 46 seconds later than the mean time thereof, by comparing these times in the above example: and therefore, we must add the Sun's motion from the node during that interval to the above mean distance $0^s\ 5^\circ\ 35'\ 2''$, which motion is found in Table XII, for 50 minutes 46 seconds, to be $2'\ 12''$. And to this we must apply the equation of the Sun's mean distance from the node, in Table XV, found by the Sun's anomaly, which, at the mean time of new Moon in example I, is $9^s\ 1^\circ\ 26'\ 19''$; and then we shall have the Sun's true distance from the node, at the true time of new Moon, as follows:

	Sun from Node. s ° ′ ″
At the mean time of new Moon in *April* 1764.	0 5 35 2
Sun's motion from the node for — 50 minutes	2 10
46 seconds	2
Sun's mean distance from node at true new Moon — —	0 5 37 14
Equation of mean distance from node, add — —	2 5 0
Sun's true distance from the ascending node — —	0 7 42 14

which, being far within the above limit of 17 degrees, shews that the Sun must then be eclipsed.

And now we shall shew how to project this, or any other eclipse, either of the Sun or Moon.

To project an Eclipse of the Sun.

In order to this, we must find the ten following elements by means of the tables.

1. The true time of conjunction of the Sun and Moon; and at that time, 2. The semidiameter of the Earth's disc, as seen from the Moon, which is equal to the Moon's horizontal parallax. 3. The Sun's distance from the solstitial colure to which he is then nearest. 4. The Sun's declination. 5. The angle of the Moon's visible path with the ecliptic. 6. The Moon's latitude. 7. The Moon's true horary motion from the Sun. 8. The Sun's semidiameter. 9. The Moon's. 10. The semidiameter of the penumbra.

We shall now proceed to find these elements for the Sun's eclipse in *April* 1764.

To find the true time of new Moon. This, by example I, p. 350, is found to be on the first day of the said month, at 30 minutes 25 seconds after X in the morning.

2. *To find the Moon's horizontal parallax, or semidiameter of the Earth's disc, as seen from the Moon.* Enter Table XVII, with the signs and degrees of the Moon's anomaly, (making proportions, because the anomaly is in the table only to every 6th degree,) and thereby take out the Moon's horizontal parallax; which, for the above time, answering to the anomaly 11^s 9° 24′ 21″, is 54′ 43″.

3. *To find the Sun's distance from the nearest solstice, viz. the beginning of Cancer, which is* 3^s *or* 90 *from the beginning of Aries.* It appears by the example on page 358 (where the Sun's place is calculated to the above time of new Moon) that the Sun's longitude from the beginning of Aries is then 0^s 12 10′ 7″, that is, the Sun's place at that time is ♈ Aries, 12° 10′ 7″.

	s	°	′	″
Therefore from — —	3	0	0	0
Subtract the Sun's longitude or place	0	12	10	7
Remains the Sun's distance from the solstice ♋ — =	2	17	49	53

Or 77° 49′ 53″: each sign containing 30 degrees.

4. *To find the Sun's delcination.* Enter Table XIV, with the signs and degrees of the Sun's true place, viz. 0^s 12°, and making proportion for the 10′ 7″, take out the Sun's declination answering to his true place, and it will be found to be 4° 49′ north.

5. *To find the Moon's latitude.* This depends on her distance from her ascending node, which is the same as the Sun's distance from it at the time of new Moon: and with this the Moon's latitude is found in Table XVI.

Now we have already found, that the Sun's equated distance from the ascending node, at the time of new Moon in *April* 1764, is 0^s 7 42′ 14″. *See the preceding page.*

Therefore, enter Table XVI, with 0 sign at the top, and 7 and 8 degrees at the left hand, and take

out 36′ and 39′, the latitude for 7°; and 41′ 51″, the latitude for 8°: and by making proportion between these latitudes for the 42′ 14″ by which the Moon's distance from the node exceeds 7 degrees; her true latitude will be found to be 40′ 18″ north-ascending.

6. *To find the Moon's true horary motion from the Sun.* With the Moon's anomaly, viz. 11^s 9° 24′ 21″, enter Table XVII, and take out the Moon's horary motion; which, by making proportion in that table, will be found to be 30′ 22″. Then, with the Sun's anomaly, 9^s 1° 26′ 16″, take out his horary motion 2′ 28″ from the same table: and subtracting the latter from the former, there will remain 27′ 54″ for the Moon's true horary motion from the Sun.

7. *To find the angle of the Moon's visible path with the ecliptic.* This, in the projection of eclipses, may be always rated at 5° 35′, without any sensible error.

8, 9. *To find the semidiameters of the Sun and Moon.* These are found in the same table, and by the same arguments, as their horary motions.—In the present case, the Sun's anomaly gives his semidiameter 16′ 6″, and the Moon's anomaly gives her semidiameter 14′ 57″.

10. *To find the semidiameter of the penumbra.* Add the Moon's semidiameter to the Sun's, and their sum will be the semidiameter of the penumbra, viz. 31′ 3″.

Now collect these elements, that they may be found the more readily when they are wanted in the construction of this eclipse.

1. True time of new Moon in *April* 1764 —	1^d	10^h 30′	25″
	°	′	″
2. Semidiameter of the Earth's disc,	0	54	43
3. Sun's dist. from the nearest solst.	77	49	53
4. Sun's declination, north	4	49	0
5. Moon's latitude, north-ascending	0	40	18

	°	′	″
6. Moon's horary motion from the Sun	0	27	54
7. Angle of the Moon's visible path with the ecliptic	5	35	0
8. Sun's semidiameter		16	6
9. Moon's semidiameter		14	57
10. Semidiameter of the penumbra		31	3

To project an Eclipse of the Sun geometrically.

Make a scale of any convenient length, as *AC*, *Plate XII. Fig. I.* and divide it into as many equal parts as the Earth's semi-disc contains minutes of a degree; which, at the time of the eclipse in *April* 1764, is 54 43′. Then, with the whole length of the scale as a radius, describe the semicircle *AMB* upon the centre *C*; which semicircle shall represent the northern half of the Earth's enlightened disc, as seen from the Sun.

Upon the centre *C* raise the straight line *CH*, perpendicular to the diameter *ACB*; so *ACB* shall be a part of the ecliptic, and *CH* its axis.

Being provided with a good sector, open it to the radius *CA* in the line of chords; and taking from thence the chord of 23½ degrees in your compasses, set it off both ways from *H*, to *g* and to *h*, in the periphery of the semi-disc; and draw the straight line *gVh*, in which the north pole of the disc will be always found.

When the Sun is in Aries, Taurus, Gemini. Cancer, Leo, and Virgo, the north pole of the Earth is enlightened by the Sun: but while the Sun is in the other six signs, the south pole is enlightened, and the north pole is in the dark.

And when the Sun is in Capricorn, Aquarius, Pisces, Aries, Taurus, and Gemini, the northern half of the Earth's axis *C* XII *P* lies to the right hand of the axis of the ecliptic, as seen from the Sun; and to the left hand, while the Sun is in the other six signs.

Open the sector till the radius (or distance of the two 90's) of the signs be equal to the length of *Vh*, and take the sine of the Sun's distance from the solstice (77° 49′ 53″) as nearly as you can guess, in your compasses, from the line of sines, and set off that distance from *V* to *P* in the line *gVh*, because the Earth's axis lies to the right hand of the axis of the ecliptic in this case, the Sun being in Aries; and draw the straight line *C* XII *P* for the Earth's axis, of which *P* is the north pole. If the Earth's axis had lain to the left hand from the axis of the ecliptic, the distance *VP* would have been set off from *V* toward *g*.

To draw the parallel of latitude of any given place, as suppose *London*, or the path of that place on the Earth's enlightened disc as seen from the Sun, from Sun-rise till Sun-set, take the following method.

Subtract the latitude of *London*, 51½° from 90° and the remainder 38½ will be the co-latitude, which take in your compasses from the line of chords, making *CA* or *CB* the radius, and set it from *h* (where the Earth's axis meets the periphery of the disc) to VI and VI, and draw the occult or dotted line VI *K* VI. Then, from the points where this line meets the Earth's disc, set off the chord of the Sun's declination 4° 49′ to *D* and *F*, and to *E* and *G*, and connect these points by the two occult lines *F* XII *G* and *DLE*.

Bisect *LK* XII in *K*, and through the point *K* draw the black line VI *K* VI. Then making *CB* the radius of a line of sines on the sector, take the co-latitude of *London* 38½ from the sines in your compasses, and set it both ways from *K*, to VI and VI.—These hours will be just in the edge of the disc at the equinoxes, but at no other time in the whole year.

With the extent *K* VI, taken into your compasses, set one foot in *K* (in the black line below the occult one) as a centre and with the other foot describe the semicircle VI, 7, 8, 9, 10, &c. and divide it into 12

equal parts. Then from these points of division, draw the occult lines 7 *p*, 8, *o n*, &c. parallel to the Earth's axis *C* XII *P*.

With the small extent *K* XII as a radius, describe the quadrantal arc XII *f*, and divide it into six equal parts, as XII *a*, *ab*, *bc*, *cd*, *de*, and *ef*; and through the division-points, *a*, *b*, *c*, *d*, *e*, draw the occult lines VII *e* V, VIII *d* IV, IX *c* III, X *b* II, and XI *a* I, all parallel to VI *K* VI, and meeting the former occult lines 7 *p*, 8 *o*, &c. in the points VII, VIII, IX, X, XI, V. IV, III, II, and I: which points shall mark the several situations of *London* on the Earth's disc, at these hours respectively, as seen from the Sun; and the elliptic curve VI VII VIII, &c. being drawn through these points shall represent the parallel of latitude, or path of *London* on the disc, as seen from the Sun, from its rising to its setting.

N. B. If the Sun's declination had been south, the diurnal path of *London* would have been on the upper side of the line VI *K* VI, and would have touched the line *DLE* in *L*.—It is requisite to divide the horary spaces into quarters (as some are in the figure) and, if possible, into minutes also.

Make *CB*, the radius of a line of chord on the sector, and taking therefrom the chord of 5° 35′, the angle of the Moon's visible path with the ecliptic, set it off from *H* to *M* on the left hand of *CH*, the axis of the ecliptic, because the Moon's latitude is north-ascending. Then draw *CM* for the axis of the Moon's orbit, and bisect the angle *MCH* by the right line *Cz*.--If the Moon's latitude had been north-descending, the axis of her orbit would have been on the right hand from the axis of the ecliptic.—*N. B.* The axis of the Moon's orbit lies the same way when her latitude is south-ascending, as when it is north-ascending; and the same way when south-descending, as when north-descending.

Take the Moon's latitude 40′ 18″ from the scale *CA* in your compasses, and set it from *i* to *x* in the

bisecting line Cz, making ix parallel to Cy: and through x, at right-angles to the axis of the Moon's orbit CM, draw the straight line $N w x y S$, for the path of the penumbra's centre over the Earth's disc. The point w in the axis of the Moon's orbit, is that where the penumbra's centre approaches nearest to the centre of the Earth's disc, and consequently is the middle of the general eclipse: the point x is that where the conjunction of the Sun and Moon falls, according to equal time by the tables; and the point y is the ecliptical conjunction of the Sun and Moon.

Take the Moon's true horary motion from the Sun, 27′ 54″, in your compasses, from the scale CA (every division of which is a minute of a degree), and with that extent make marks along the path of the penumbra's centre; and divide each space from mark to mark into sixty equal parts or horary minutes, by dots; and set the hours to every 60th minute in such a manner, that the dot signifying the instant of new Moon by the tables, may fall into the point x, half way between the axis of the Moon's orbit, and the axis of the ecliptic; and then the rest of the dots will shew the points of the Earth's disc, where the penumbra's centre is at the instants denoted by them, in its transit over the Earth.

Apply one side of a square to the line of the penumbra's path, and move the square backward and forward, until the other side of it cuts the same hour and minute (as at m and n) both in the path of *London*, and in the path of the penumbra's centre: and the particular minute or instant which the square cuts at the same time in both paths, shall be the instant of the visible conjunction of the Sun and Moon, or greatest obscuration of the Sun, at the place for which the construction is made, namely, *London*, in the present example; and this instant is at 47½ minutes past X o'clock in the morning; which is 17 minutes 5 seconds later than the tabular time of true conjunction.

Take the Sun's semidiameter, 16′ 6″, in your compasses, from the scale *CA*, and setting one foot in the path of *London* at *m*, namely at 47½ minutes past X, with the other foot describe the circle *UY*, which shall represent the Sun's disc as seen from *London* at the greatest obscuration.—Then take the Moon's semidiameter, 14′ 57″, in your compasses, from the same scale; and setting one foot in the path of the penumbra's centre at *m*, 47½ minutes after X; with the other foot describe the circle *TY* for the Moon's disc, as seen from *London*, at the time when the eclipse is at the greatest; and the portion of the Sun's disc which is hid or cut off by the Moon's, will shew the quantity of the eclipse at that time; which quantity may be measured on a line equal to the Sun's diameter, and divided into 12 equal parts for digits.

Lastly, take the semidiameter of the penumbra 31′ 3″, from the scale *CA* in your compasses; and setting one foot in the line of the penumbra's central path, on the left hand from the axis of the ecliptic, direct the other foot toward the path of *London;* and carry that extent backward and forward till both the points of the compasses fall into the same instant in both the paths; and that instant will denote the time when the eclipse begins at *London*.—Then, do the like on the right hand of the axis of the ecliptic; and where the points of the compasses fall into the same instant in both the paths, that instant will be the time when the eclipse ends at *London*.

These trials give 20 minutes after IX in the morning for the beginning of the eclipse at *London*, at the points *N* and *O;* 47½ minutes after X, at the points *m* and *n*, for the time of greatest obscuration; and 18 minutes after XII, at *R* and *S*, for the time when the eclipse ends; according to mean or equal time.

From these times we must subtract the equation of natural days, *viz.* 3 minutes 48 seconds, in leap-year *April* 1, and we shall have the apparent times;

namely, IX hours 16 minutes 12 seconds for the beginning of the eclipse, X hours 43 minutes 42 seconds for the time of greatest obscuration, and XII hours 14 minutes 12 seconds for the time when the eclipse ends.—But the best way is to apply this equation to the true equal time of new Moon, before the projection be begun; as is done in example I. For the motion or position of places on the Earth's disc answers to apparent or solar time.

In this construction, it is supposed that the angle under which the Moon's disc is seen, during the whole time of the eclipse, continues invariably the same and that the Moon's motion is uniform and rectilinear during that time.—But these suppositions do not exactly agree with the truth; and therefore, supposing the elements given by the tables to be accurate, yet the times and phases of the eclipse, deduced from its construction, will not answer exactly to what passes in the heavens; but may be at least two or three minutes wrong, though done with the greatest care.—Moreover, the paths of all places of considerable latitudes are nearer the centre of the Earth's disc, as seen from the Sun, than those constructions make them; because the disc is projected as if the Earth were a perfect sphere, although it is known to be a spheroid. Consequently, the Moon's shadow will go farther northward in all places of northern latitude, and farther southward in all places of southern latitude, than it is shewn to do in these projections.—According to *Mayer*'s tables, this eclipse will be about a quarter of an hour sooner than either these tables, or Mr. *Flamstead*'s, or Dr. *Halley*'s, make it: and *Mayer*'s tables do not make it annular at *London*.

The projection of Lunar Eclipses.

When the Moon is within 12 degrees of either of her nodes, at the time when she is full, she will be eclipsed, otherwise not.

We find by example II. page 351, that at the time of mean full Moon in *May*, 1762, the Sun's distance from the ascending node was only 4° 49′ 35″, and the Moon being then opposite to the Sun, must have been just as near her descending node, and was therefore eclipsed.

The elements for constructing an eclipse of the Moon are eight in number, as follows:

1. The true time of full Moon: and at that time. 2. The Moon's horizontal parallax. 3. The Sun's semidiameter. 4. The Moon's. 5. The semidiameter of the Earth's shadow at the Moon. 6. The Moon's latitude. 7. The angle of the Moon's visible path with the ecliptic. 8. The Moon's true horary motion from the Sun.—Therefore,

1. *To find the true time of full Moon.* Work as already taught in the precepts.—Thus we have the true time of full Moon in *May*, 1762, (see example II. page 351,) on the 8th day, at 50 minutes 50 seconds past III o'clock in the morning.

2. *To find the Moon's horizontal parallax.* Enter Table XVII. with the Moon's mean anomaly (at the above full) 9ˢ 2° 42′ 42″, and thereby take out her horizontal parallax; which by making the requisite proportion, will be found to be 57′ 20″.

3, 4. *To find the semidiameters of the Sun and Moon.* Enter Table XVII, with their respective anomalies, the Sun's being 10ˢ 7° 27′ 45″ (by the above example), and the Moon's 9ˢ 2° 42′ 42″; and thereby take out their respective semidiameters: the Sun's 15′ 56″, and the Moon's 15′ 39″.

5. *To find the semidiameter of the Earth's shadow at the Moon.* Add the Sun's horizontal paral-

lax, which is always 10″, to the Moon's, which in the present case is 57′ 20″, the sum will be 57′ 30″, from which subtract the Sun's semidiameter 15′ 56″, and there will remain 41′ 34″ for the semidiameter of that part of the Earth's shadow which the Moon then passes through.

6. *To find the Moon's latitude.* Find the Sun's true distance from the ascending node (as already taught in page 361) at the true time of full Moon; and this distance, increased by six signs, will be the Moon's true distance from the same node; and consequently the argument for finding her true latitude, as shewn in page 363.

Thus, in example II. the Sun's mean distance from the ascending node was 0ˢ 4° 49′ 35″, at the time of mean full Moon: but it appears by the example, that the true time thereof was 6 hours 33 minutes 38 seconds sooner than the mean time, and therefore we must subtract the Sun's motion from the node (found in Table XII, page 342) during this interval, from the above mean distance 0ˢ 4° 49′ 35″, in order to have his mean distance from it at the true time of full Moon.—Then to this apply the equation of his mean distance from the node found in Table XV. by his mean anomaly 10ˢ 7° 27′ 45″; and lastly, add six signs: so shall the Moon's true distance from the ascending node be found as follows:

		s	°	′	″
Sun from node at mean full Moon		0	4	49	35
His motion from it in	6 hours			15	35
	33 minutes			1	26
	38 seconds				2
Sum, subtract from the uppermost line				17	3
Remains his mean distance at true full Moon — —		0	4	32	32

	s	°	′	″
Equation of his mean distance, add	0	1	38	0
Sun's true distance from the node	0	6	10	32
To which add	6	0	0	0
And the sum will be	6	6	10	32

which is the Moon's true distance from her ascending node at the true time of her being full; and consequently the argument for finding her true latitude at that time.—Therefore, with this argument, enter Table XVI. making proportion between the latitudes belonging to the 6th and 7th degree of the argument at the left hand (the signs being at the top) for the 10′ 32″, and it will give 32′ 21″ for the Moon's true latitude, which appears by the table to be south-descending.

7. *To find the angle of the Moon's visible path with the ecliptic.* This may be stated at 5° 35′, without any error of consequence in the projection of the eclipse.

8. *To find the Moon's true horary motion from the Sun.* With their respective anomalies take out their horary motions from Table XVII. in page 346; and the Sun's horary motion subtracted from the Moon's, leaves remaining the Moon's true horary motion from the Sun: in the present case 30′ 52″.

Now collect these elements together for use.

	D.	H.	M.	S.
1. True time of full Moon in *May*, 1762	8	3	50	50
		°	′	″
2. Moon's horizontal parallax		0	57	20
3. Sun's semidiameter		0	15	56
4. Moon's semidiameter		0	15	39
5. Semidiameter of the Earth's shadow at the Moon		0	41	34

	°	′	″
6. Moon's true latitude, south-descending	0	32	21
7. Angle of her visible path with the ecliptic	5	35	0
8. Her true horary motion from the Sun	0	30	52

Plate XII. These elements being found for the construction of the Moon's eclipse in *May* 1762, proceed as follows:

Fig. II Make a scale of any convenient length, as *W X*, and divide it into 60 equal parts, each part standing for a minute of a degree.

Draw the right line *A C B* (Fig. 3.) for part of the ecliptic, and *C D* perpendicular to it for the southern part of its axis; the Moon having south latitude.

Add the semidiameters of the Moon and Earth's shadow together, which, in this eclipse, will make 57′ 13″; and take this from the scale in your compasses, and setting one foot in the point *C*, as a centre, with the other foot describe the semicircle *A D B*; in one point of which the Moon's centre will be at the beginning of the eclipse, and in another at the end of it.

Take the semidiameter of the Earth's shadow, 41′ 34″, in your compasses from the scale, and setting one foot in the centre *C*, with the other foot describe the semicircle *K L M* for the southern half of the Earth's shadow, because the Moon's latitude is south in this eclipse.

Make *C D* the radius of a line of chords on the sector, and set off the angle of the Moon's visible path with the ecliptic, 5° 35′, from *D* to *E*, and draw the right line *C F E* for the southern half of the axis of the Moon's orbit, lying to the right hand from the axis of the ecliptic *CD*, because the Moon's latitude is south-descending.—It would have been the same way (on the other side of the ecliptic) if her latitude had been north-descending; but contrary

in both cases, if her latitude had been either north-ascending or south-ascending.

Bisect the angle *D C E* by the right line *C g*, in which line the true equal time of opposition of the Sun and Moon falls, as given by the tables.

Take the Moon's latitude, 32′ 21″, from the scale with your compasses, and set it from *C* to *G*, in the line *C G g;* and through the point *G*, at right angles to *C F E*, draw the right line *P H G F N* for the path of the Moon's centre. Then *F* shall be the point in the Earth's shadow, where the Moon's centre is at the middle of the eclipse; *G*, the point where her centre is at the tabular time of her being full; and *H*, the point where her centre is at the instant of her ecliptical opposition.

Take the Moon's horary motion from the Sun, 30′ 52″, in your compasses from the scale; and with that extent make marks along the line of the Moon's path, *P G N:* Then divide each space from mark to mark, into 60 equal parts, or horary minutes, and set the hours to the proper dots in such a manner, that the dot signifying the instant of full Moon, (viz. 50 minutes 50 seconds after III in the morning) may be in the point *G*, where the line of the Moon's path cuts the line that bisects the angle *D C E*.

Take the Moon's semidiameter, 15′ 39″, in your compasses from the scale, and with that extent, as a radius, upon the points *N*, *F*, and *P*, as centres, describe the circle *Q* for the Moon at the beginning of the eclipse, when she touches the Earth's shadow at *V;* the circle *R* for the Moon at the middle of the eclipse; and the circle *S* for the Moon at the end of the eclipse, just leaving the Earth's shadow at *W*.

The point *N* denotes the instant when the eclipse begins, namely, at 15 minutes 10 seconds after II in the morning; the point *F* the middle of the eclipse, at 47 minutes 45 seconds past III; and the point *P* the end of the eclipse, at 18 minutes after V.—At the greatest obscuration the Moon is 10 digits eclipsed.

Concerning an ancient Eclipse of the Moon.

It is recorded by *Ptolemy*, from *Hipparchus*, that on the 22d of *September*, the year 201 before the first year of Christ, the Moon rose so much eclipsed at *Alexandria*, that the eclipse must have begun about half an hour before she rose.

Mr. *Carey* puts down the eclipse in his Chronology as follows, among several other ancient ones, recorded by different authors:

Jul. Per. 4513. *Sept.* 22.	Ecl. ● *Per Calip.* 2 *An.* 54. *Hor.* 7. *P. M. Alexandr. Dig. eccl.* 10. [*Ptolem. l.* 4. *c.* 11.]	*Nabonassar.* 547. *Mesor.* 16.

That is, in the 4513th year of the *Julian* period, which was the 547th year from *Nabonassar*, and the 54th year of the second *Calipic* period, on the 16th day of the month *Mesori*, (which answers to the 22d of *September*) the Moon was 10 digits eclipsed at *Alexandria*, at 7 o'clock in the evening.

Now, as our Saviour was born (according to the *Dionysian* or vulgar æra of his birth) in the 4713th year of the *Julian* period, it is plain that the 4513th year of that period was the 200th year before the year of Christ's birth; and consequently 201 years before the year of Christ 1.

And in the year 201, on the 22d of *September*, it appears by example V. (page 354) that the Moon was full at 26 minutes 28 seconds past VII in the evening, in the meridian of *Alexandria*.

At that time, the Sun's place was Virgo 26° 14′, according to our tables; so that the Sun was then within 4 degrees of the autumnal equinox; and according to calculation he must have set at *Alexandria* about 5 minutes after VI, and about one degree north of the west.

The Moon being full at that time, would have risen just at Sun-set, about one degree south of the east,

if she had been in either of her nodes, and her visible place not depressed by parallax.

But her parallactic depression (as appears from her anomaly, viz. 10ˢ 6° nearly) must have been 55′ 17″; which exceeded her whole diameter by 24′ 53″; but then, she must have been elevated 33′ 45″ by refraction; which, subtracted from her parallax, leaves 21′ 32″ for her visible or apparent depression.

And her true latitude was 30¼ north-descending, which being contrary to her apparent depression, and greater than the same by 8′ 58″, her true time of rising must have been just about VI o'clock. Now, as the Moon rose about one degree south of the east at *Alexandria*, where the visible horizon is land, and not sea, we can hardly imagine her to have been less than 15 or 20 minutes of time above the true horizon before she was visible.

It appears by Fig. 4, which is a delineation of this eclipse reduced to the time at *Alexandria*, that the eclipse began at 53 minutes after V in the evening; and consequently 7 minutes before the Moon was in the true horizon; to which if we add 20 minutes for the interval between her true rising and her being visible, we shall have 27 minutes for the time that the eclipse was begun before the Moon was visibly risen. The middle of this eclipse was at 30 minutes past VII, when its quantity was almost 10 digits, and its ending was at 6 minutes past IX in the evening. So that our tables come as near to the recorded time of this eclipse as can be expected, after an elapse of 1960 years.

CHAP. XVIII.

Of the fixed Stars.

Why the fixed stars appear bigger when viewed by the bare eye, than when seen through a telescope.

354. THE Stars are said to be fixed, because they have been generally observed to keep at the same distances from each other, their apparent diurnal revolution being caused solely by the Earth's turning on its axis. They appear of a sensible magnitude to the bare eye, because the retina is affected not only by the rays of light which are emitted directly from them, but by many thousands more, which falling upon our eye-lids, and upon the aerial particles about us, are reflected into our eyes so strongly, as to excite vibrations not only in those points of the retina where the real images of the stars are formed, but also in other points at some distance round about. This makes us imagine the stars to be much bigger than they would appear, if we saw them only by the few rays coming directly from them, so as to enter our eyes without being intermixed with others. Any one may be sensible of this, by looking at a star of the first magnitude through a long narrow tube; which, though it takes in as much of the sky as would hold a thousand such stars, it scarce renders *that* one visible.

A proof that they shine by their own light.

The more a telescope magnifies, the less is the aperture through which the star is seen, and consequently the fewer rays it admits into the eye. Now since the stars appear less in a telescope which magnifies 200 times, than they do to the bare eye, insomuch that they seem to be only indivisible points, it proves at once that the stars are at immense distances from us, and that they shine by their own proper light. If they shone by borrowed light, they would be as invisible without telescopes as the satellites of Jupiter are; for these satellites appear

bigger when viewed with a good telescope than the largest fixed stars do.

355. The number of stars discoverable in either hemisphere, by the naked eye, is not above a thousand. This at first may appear incredible, because they seem to be without number: but the deception arises from our looking confusedly upon them, without reducing them into any order. For look but stedfastly upon a pretty large portion of the sky, and count the number of stars in it, and you will be surprised to find them so few. And, if one considers how seldom the Moon meets with any stars in her way, although there are as many about her path as in other parts of the heavens, he will soon be convinced that the stars are much thinner sown than he was aware of. The *British* catalogue, which, besides the stars visible to the bare eye, includes a great number which cannot be seen without the assistance of a telescope, contains no more than 3000 in both hemispheres.

Their number much less than is generally imagined.

356. As we have incomparably more light from the Moon than from all the stars together, it is the greatest absurdity to imagine that the stars were made for no other purpose than to cast a faint light upon the Earth: especially since many more require the assistance of a good telescope to find them out, than are visible without that instrument. Our Sun is surrounded by a system of planets and comets; all of which would be invisible from the nearest fixed star. And from what we already know of the immense distance of the stars, the nearest may be computed at 32,000,000,000,000 of miles from us, which is further than a cannon-ball would fly in 7,000,000 of years. Hence it is easy to prove, that the Sun, seen from such a distance, would appear no bigger than a star of the first magnitude. From all this it is highly probable that each star is a Sun to a system of worlds moving round it, though unseen by us; especially as the doctrine of plurality of worlds is rational, and greatly manifests the Power, Wisdom, and Goodness of the Great Creator.

The absurdity of supposing the stars were made only to shine upon us in the night.

Their different magnitudes:

357. The stars, on account of their apparently various magnitudes, have been distributed into several classes or orders. Those which appear largest, are called *stars of the first magnitude;* the next to them in lustre, *stars of the second magnitude;* and so on to the *sixth;* which are the smallest that are visible to the bare eye. This distribution having been made long before the invention of telescopes, the stars which cannot be seen without the assistance of these instruments, are distinguished by the name of *telescopic stars.*

And division into constellations.

358. The ancients divided the starry sphere into particular constellations, or systems of stars, according as they lay near one another, so as to occupy those spaces with the figures of different sorts of animals or things would take up, if they were there delineated. And those stars which could not be brought into any particular constellation, were called *unformed stars.*

The use of this division.

359. This division of the stars into different constellations or asterisms, serves to distinguish them from one another, so that any particular star may be readily found in the heavens by means of a celestial globe; on which the constellations are so delineated as to put the most remarkable stars into such parts of the figures as are most easily distinguished. The number of the ancient constellations is 48, and upon our present globes about 70. On *Senex*'s globes, *Bayer*'s letters are inserted; the first in the Greek alphabet being put to the biggest star in each constellation, the second to the next, and so on: by which means, every star is as easily found as if a name were given to it. Thus, if the star γ in the constellation of the *Ram* be mentioned, every astronomer knows as well what star is meant, as if it were pointed out to him in the heavens.

The zodiac.

360. There is also a division of the heavens into three parts. 1. The *zodiac* (ζωδιακος) from ζωδιον *zodion* an animal, because most of the constellations in it, which are twelve in number, are the figures of

animals: as *Aries* the Ram, *Taurus* the Bull, *Gemini* the twins, *Cancer* the Crab, *Leo* the Lion, *Virgo* the Virgin, *Libra* the Balance, *Scorpio* the Scorpion, *Sagittarius* the Archer, *Capricornus* the Goat, *Aquarius* the Water-bearer, and *Pisces* the Fishes. The zodiac goes quite round the heavens: it is about 16 degrees broad, so that it takes in the orbits of all the planets, and likewise the orbit of the Moon. Along the middle of this zone or belt is the ecliptic, or circle which the Earth describes annually as seen from the Sun; and which the Sun appears to describe as seen from the Earth. 2. All that region of the heavens, which is on the north side of the zodiac, containing 21 constellations. And, 3d, That on the south side, containing 15.

The manner of dividing it by the ancients.

361. The ancients divided the *zodiac* into the above 12 constellations or signs in the following manner. They took a vessel with a small hole in the bottom, and having filled it with water, suffered the same to distil drop by drop into another vessel set beneath to receive it; beginning at the moment when some star rose, and continuing until it rose the next following night. The water falling down into the receiver, they divided into twelve equal parts; and having two other small vessels in readiness, each of them fit to contain one part, they again poured all the water into the upper vessel, and, observing the rising of some star in the *zodiac*, they at the same time suffered the water to drop into one of the small vessels; and as soon as it was full, they shifted it, and set an empty one in its place. When each vessel was full, they took notice what star of the *zodiac* rose; and though this could not be done in one night, yet in many they observed the rising of twelve stars or points, by which they divide the *zodiac* into twelve parts.

362. The names of the constellations and the number of stars observed in each of them by different astronomers, are as follows :

The ancient Constellations.		*Ptolemy.*	*Tycho.*	*Hevel.*	*Flamst.*
Ursa minor	The Little Bear	8	7	12	24
Ursa major	The Great Bear	35	29	73	87
Draco	The Dragon	31	32	40	80
Cepheus	Cepheus	13	4	51	35
Bootes, *Arctophilax*		23	18	52	54
Corona Borealis	The Northern Crown	8	8	8	21
Hercules, *En-gonasin*	Hercules kneeling	29	28	45	113
Lyra	The Harp	10	11	17	21
Cygnus, *Gallina*	The Swan	19	18	47	81
Cassiopea	The Lady in her Chair	13	26	47	55
Perseus	Perseus	29	29	46	59
Auriga	The Waggoner	14	9	40	66
Serpentarius, *Ophiuchus*	Serpentarius	29	15	40	74
Serpens	The Serpent	18	13	22	64
Sagitta	The Arrow	5	5	5	18
Aquila, *Vultur*	The Eagle	15	12	23	71
Antinous	Antinous		3	19	
Delphinus	The Dolphin	10	10	14	18
Equulus, *Equi sectio*	The Horse's Head	4	4	6	10
Pegasus, *Equus*	The Flying Horse	20	19	38	89
Andromeda	Andromeda	23	23	47	66
Triangulum	The Triangle	4	4	12	16
Aries	The Ram	18	21	27	66
Taurus	The Bull	44	43	51	141
Gemini	The Twins	25	25	38	[illegible]
Cancer	The Crab	23	15	29	83
Leo	The Lion	35	30	49	95
Coma Berenices	Berenice's Hair		14	21	43
Virgo	The Virgin	32	33	50	110
Libra, *Chelæ*	The Scales	17	10	20	51
Scorpius	The Scorpion	24	10	20	44
Sagittarius	The Archer	31	14	22	69
Capricornus	The Goat	28	28	29	51
Aquarius	The Water-Bearer	45	41	47	108
Pisces	The Fishes	38	36	39	113
Cetus	The Whale	22	21	45	97
Orion	Orion	38	42	62	78
Eridanus, *Fluvius*	Eridanus, *the River*	34	10	27	84
Lepus	The Hare	12	13	16	19
Canis major	The Great Dog	29	13	21	31
Canis minor	The Little Dog	2	2	13	14

The ancient Constellations.		*Ptolemy.*	*Tycho.*	*Hevel.*	*Flamst.*
Argo	The Ship	45	3	4	64
Hydra	The Hydra	27	19	31	60
Crater	The Cup	7	3	10	31
Corvus	The Crow	7	4		9
Centaurus	The Centaur	37			35
Lupus	The Wolf	19			24
Ara	The Altar	7			9
Corono Australis	The Southern Crown	13			12
Piscis Australis	The Southern Fish	18			24

The New Southern Constellations.

Columba Naochi	Noah's Dove	10
Robur Carolinum	The Royal Oak	12
Grus	The Crane	13
Phœnix	The Phenix	13
Indus	The Indian	12
Pavo	The Peacock	14
Apus, *Avis Indica*	The Bird of Paradise	11
Apis, *Musca*	The Bee or Fly	4
Chamæleon	The Chameleon	10
Triangulum Australis	The South Triangle	5
Piscis volans, *Passer*	The Flying Fish	8
Dorado, *Xiphias*	The Sword Fish	6
Toucan	The American Goose	9
Hydrus	The Water Snake	10

Hevelius's Constellations made out of the unformed Stars.

		Hevelius.	*Flamst.*
Lynx	The Lynx	19	44
Leo minor	The Little Lion		53
Asteron & Chara	The Greyhounds	23	25
Cerberus	Cerberus	4	
Vulpecula & Anser	The Fox and Goose	27	35
Scutum Sobieski	Sobieski's Shield	7	
Lacerta	The Lizard		16
Camelopardalus	The Camelopard	32	58
Monoceros	The Unicorn	19	31
Sextans	The Sextant	11	41

363. There is a remarkable track round the heavens, called the *Milky Way*, from its peculiar whiteness, which is found, by means of the telescope, to be owing to a vast number of very small stars, that

The *Milky Way.*

are situate in that part of the heavens. This track appears single in some parts, in others double.

Lucid spots

364. There are several little whitish spots in the heavens, which appear magnified, and more luminous when seen through telescopes; yet without any stars in them. One of these is in *Andromeda's* girdle, and was first observed *A. D.* 1612, by *Simon Marius*: it has some whitish rays near its middle, is liable to several changes, and is sometimes invisible. Another is near the ecliptic, between the head and bow of *Sagittarius*: it is small, but very luminous. A third is on the back of the *Centaur*, which is too far south to be seen in *Britain*. A fourth, of a smaller size, is before *Antinous's* right foot, having a star in it which makes it appear more bright. A fifth is in the constellation of *Hercules*, between the stars ζ and η, which spot, though but small, is visible to the bare eye, if the sky be clear, and the Moon absent.

Cloudy stars.

365. *Cloudy stars* are so called from their misty appearance. They look like dim stars to the naked eye; but through a telescope they appear broad illuminated parts of the sky; in some of which is one star, in others more. Five of these are mentioned by *Ptolemy*. 1. One at the extremity of the right hand of *Perseus*. 2. One in the middle of the *Crab*. 3. One, unformed, near the sting of the *Scorpion*. 4. The eye of *Sagittarius*. 5. One in the head of *Orion*. In the first of these appear more stars through the telescope than in any of the rest, although 21 have been counted in the head of *Orion*, and above forty in that of the *Crab*. Two are visible in the eye of *Sagittarius* without a telescope, and several more with it. *Flamstead* observed a cloudy star in the bow of *Sagittarius*, containing many small stars: and the star *d* above *Sagittarius's* right shoulder is encompassed with several more. Both *Cassini* and *Flæmstead* discovered one between the *Great* and *Little Dog*, which is very full of stars,

visible only by the telescope. The two whitish spots near the south pole, called the *Magellanic clouds* by sailors, which to the bare eye resemble part of the Milky Way, appear through telescopes to be a mixture of small clouds and stars. But the most remarkable of all the cloudy stars is that in the middle of *Orion's sword*, where seven stars (of which three are very close together) seem to shine through a cloud, very lucid near the middle, but faint and ill-defined about the edges. It looks like a gap in the sky, through which one may see (as it were) part of a much brighter region. Although most of these spaces are but a few minutes of a degree in breadth, yet, since they are among the fixed stars, they must be spaces larger than what is occupied by our solar system; and in which there seems to be a perpetual uninterrupted day, among numberless worlds, which no human art ever can discover.

Magellanic clouds

366. Several stars are mentioned by ancient astronomers, which are not now to be found; and others are now visible to the bare eye, which are not recorded in the ancient catalogue. *Hipparchus* observed a new star about 120 years before CHRIST; but he has not mentioned in what part of the heavens it was seen, although it occasioned his making a catalogue of the stars; which is the most ancient that we have.

Changes in the heavens.

The first *new star* that we have any good account of, was discovered by *Cornelius Gemma* on the 8th of *November*, A. D. 1572, in the chair of *Cassiopea*. It surpassed *Sirius* in brightness and magnitude; and was seen for 16 months successively. At first it appeared bigger than *Jupiter*, to some eyes, by which it was seen at mid-day; afterwards it decayed gradually both in magnitude and lustre, until *March* 1573, when it became invisible.

New stars

On the 13th of *August* 1596, *David Fabricius* observed the *Stella Mira*, or wonderful star, in the *neck* of the *Whale*; which has been since found to appear and disappear periodically seven times in six

years, continuing in the greatest lustre for 15 days together; and is never quite extinguished.

In the year 1600, *William Jansenius* discovered a changeable star in the *neck* of the *Swan;* which, in time, became so small as to be thought to disappear entirely, till the years 1657, 1658, and 1659, when it recovered its former lustre and magnitude, but soon decayed; and is now of the smallest size.

In the year 1604, *Kepler* and many of his friends saw a new star near the heel of the right foot of *Serpentarius*, so bright and sparkling, that it exceeded any thing they had ever seen before; and took notice that it was every moment changing into some of the colours of the rainbow, except when it was near the horizon, at which time it was generally white. It surpassed *Jupiter* in magnitude, which was near it all the month of *October*, but easily distinguished from *Jupiter* by the steady light of that planet. It disappeared between *October* 1605, and the *February* following, and has not been seen since that time.

In the year 1670, *July* 15, *Hevelius* discovered a new star, which in *October* was so decayed as to be scarce perceptible. In *April* following it regained its lustre, but wholly disappeared in *August*. In *March* 1672, it was seen again, but very small; and has not since been visible.

In the year 1686, a new star was discovered by *Kirch*, which returns periodically in 404 days.

In the year 1672, *Cassini* saw a star in the *neck* of the *Bull*, which he thought was not visible in *Tycho's* time; nor when *Bayer* made his figures.

Cannot be comets.

367. Many stars, beside those above-mentioned, have been observed to change their magnitudes; and as none of them could ever be perceived to have tails, it is plain they could not be comets; especially as they had no parallax, even when largest and brightest. It would seem that the periodical stars have vast clusters of dark spots, and very slow rotations on their axes; by which means, they must disappear

when the side covered with spots is turned towards us. And as for those which break out all of a sudden with such lustre, it is by no means improbable that they are Suns whose fuel is almost spent, and again supplied by some of their comets falling upon them, and occasioning an uncommon blaze and splendour for some time: which indeed appears to be the greatest use of the cometary part of any system*.

Some stars change their places

Some of the stars, particularly *Arcturus*, have been observed to change their places above a minute of a degree with respect to others. But whether this be owing to any real motion in the stars themselves, must require the observations of many ages to determine. If our solar system change its place with regard to absolute space, this must in process of time occasion an apparent change in the distances of the stars from each other: and in such a case, the places of the nearest stars to us being more affected than those which are very remote, their relative positions must seem to alter, though the stars themselves were really immoveable. On the other hand, if our own system be at rest, and any of the stars in real motion, this must vary their positions; and the more so, the nearer they are to us, or the swifter their motions are; or the

* M. *Maupertuis*, in his Dissertation on the figures of the Celestial Bodies (p. 91—93), is of opinion that some stars, by their prodigious quick rotations on their axes, may not only assume the figures of oblate spheroids, but that by the great centrifugal force arising from such rotations, they may become of the figures of mill-stones; or be reduced to flat circular planes, so thin as to be quite invisible when their edges are turned toward us; as Saturn's ring is in such positions. But when any eccentric planets or comets go round any flat star, in orbits much inclined to its equator, the attraction of the planets or comets in their perihelions must alter the inclination of the axis of that star; on which account it will appear more or less large and luminous, as its broad side is more or less turned toward us. And thus he imagines we may account for the apparent changes of magnitude and lustre in those stars, and likewise for their appearing and disappearing.

more proper the direction of their motion is for our perception.

The ecliptic less oblique now to the equator than formerly.

368. The obliquity of the ecliptic to the equinoctial is found at present to be above the third part of a degree less than *Ptolemy* found it. And most of the observers after him found it do decrease gradually down to *Tycho*'s time. If it be objected, that we cannot depend on the observations of the ancients, because of the incorrectness of their instruments; we have to answer, that both *Tycho* and *Flamstead* are allowed to have been very good observers; and yet we find that *Flamstead* makes this obliquity 2½ minutes of a degree less than *Tycho* did, about 100 years before him: and as *Ptolemy* was 1324 years before *Tycho*, so the gradual decrease answers nearly to the difference of time between these three astronomers. If we consider, that the Earth is not a perfect sphere, but an oblate spheroid, having its axis shorter than its equatorial diameter; and that the Sun and Moon are constantly acting obliquely upon the greater quantity of matter about the equator, pulling it as it were toward a nearer and nearer coincidence with the ecliptic; it will not appear improbable that these actions should gradually diminish the angle between those planes. Nor is it less probable that the mutual attraction of all the planets should have a tendency to bring their orbits to a coincidence; but this change is too small to become sensible in many ages.*

* M. de la Grange has demonstrated, in the most satisfactory manner, that no *permanent* change can take place in the magnitudes, figures, or inclinations, of the planetary orbits; and that the *periodical* changes are confined within very narrow limits: the ecliptic therefore, will *never* coincide with the equator, nor change its inclination above 3 degrees. In short, the solar planetary system oscillates, as it were, round a medium state, from which it never swerves very far. See note subjoined to p. 116.

CHAP. XXI.

Of the Division of Time. A perpetual Table of New Moons. The Times of the Birth and Death of CHRIST. *A Table of remarkable Æras or Events.*

369. THE parts of time are, *seconds, minutes, hours, days, years, cycles, ages, and periods.*

370. The original standard, or integral measure A year.
of time, is a year; which is determined by the revolution of some celestial body in its orbit, viz. the *Sun* or *Moon*.

371. The time measured by the Sun's revolution Tropical year.
in the ecliptic, from any equinox or solstice to the same again, is called the *solar* or *tropical year*, which contains 365 days, 5 hours, 48 minutes, 57 seconds; and is the only proper or natural year, because it always keeps the same seasons to the same months.

372. The quantity of time measured by the Sun's Sidereal year.
revolution as from any fixed star to the same star again, is called the *sidereal year;* which contains 365 days, 6 hours, 9 minutes, 14½ seconds, and is 20 minutes 17½ seconds longer than the true solar year.

373. The time measured by twelve revolutions of Lunar year.
the Moon from the Sun to the Sun again, is called the *lunar year;* it contains 354 days, 8 hours, 48 minutes, 36 seconds; and is therefore 10 days, 21 hours, 0 minutes, 21 seconds shorter than the solar year. This is the foundation of the epact.

374. The *civil year* is that which is in common Civil year.
use among the different nations of the world; of which, some reckon by the lunar, but most by the solar. The civil solar year contains 365 days, for three years running, which are called *common years;* and then comes in what is called the *bissextile* or

leap-year, which contains 366 days. This is also called the *Julian year*, on account of *Julius Cæsar*, who appointed the intercalary day every fourth year, thinking thereby to make the civil and solar year keep pace together. And this day, being added to the 23d of *February*, which in the *Roman* calendar was the sixth of the Calends of *March*, that sixth day was twice reckoned, or the 23d and 24th were reckoned as one day; and was called *Bis sextus dies*, and thence came the name *bissextile* for that year. But in our common almanacks this day is added at the end of *February*.

Lunar year.

375. The *civil lunar year* is also common or intercalary. The common year consists of 12 lunations, which contain 354 days; at the end of which the year begins again. The *intercalary*, or *embolimic* year, is that wherein a month was added to adjust the lunar year to the solar. This method was used by the *Jews*, who kept their account by the lunar motions. But by intercalating no more than a month of 30 days, which they called *Ve-Adar*, every third year, they fell 3 ¾ days short of the solar year in that time.

Roman year.

376. The *Romans* also used the *lunar embolimic year* at first, as it was settled by *Romulus* their first king, who made it to consist only of ten months or lunations; which fell 61 days short of the solar year, and so their year became quite vague and unfixed; for which reason they were forced to have a table published by the high-priests, to inform them when the spring and other seasons began. But *Julius Cæsar*, as already mentioned, § 374, taking this troublesome affair into consideration, reformed the calendar, by making the year to consist of 365 days 6 hours.

The original of the *Gregorian* or new style.

377. The year thus settled, is what was used in *Britain* till *A. D.* 1752: but as it is somewhat more than 11 minutes longer than the *solar tropical year*, the times of the equinoxes go backward, and fall earlier by one day in about 130 years. In the time

of the *Nicene council* (A. D. 325), which was 1439 years ago, the vernal equinox fell on the 21st of *March:* and if we divide 1444 by 130, it will quote 11, which is the number of days the equinox has fallen back since the council of *Nice.* This causing great disturbances, by unfixing the times of the celebration of *Easter*, and consequently of all the other moveable feasts, pope *Gregory* the XIII, in the year 1582, ordered ten days to be at once stricken out of that year; and the next day after the fourth of *October* was called the fifteenth. By this means, the vernal equinox was restored to the 21st of *March;* and it was endeavoured, by the omission of three intercalary days in 400 years, to make the civil or political year keep pace with the solar for the time to come. This new form of the year is called the *Gregorian account*, or *new style;* which is received in all countries where the pope's authority is acknowledged, and ought to be in all places where truth is regarded.

378. The principal division of the year is into *months*, which are of two sorts, namely, *astronomical* and *civil.* The astronomical month is the time in which the Moon runs through the *zodiac*, and is either *periodical* or *synodical.* The periodical month is the time spent by the Moon in making one complete revolution from any point of the zodiac to the same again; which is $27^d\ 7^h\ 43^m$. The synodical month, called a *lunation*, is the time contained between the Moon's parting with the Sun at a conjunction, and returning to him again; which is $29^d\ 12^h\ 44^m$. The civil months are those which are framed for the uses of civil life; and are different as to their names, number of days, and times of beginning, in several different countries. The first month of the *Jewish Year* fell, according to the Moon, in our *August* and *September*, old style; the second in *September* and *October;* and so on. The first month of the *Egyptian year* began on the 29th of our *August.* The first month of the *Arabic* and *Turkish* Months

year began the 16th of *July*. The first month of the *Grecian year* fell, according to the Moon, in *June* and *July*, the second in *July* and *August*, and so on, as in the following table.

379. A month is divided into four parts called *weeks*, and a week into seven parts called *days*; so that in a *Julian* year there are 13 such months, or 52 weeks, and one day over. The *Gentiles* gave the names of the Sun, Moon, and planets, to the days of the week. To the first, the name of the *Sun*; to the second, of the *Moon*; to the third, of *Mars*; to the fourth, of *Mercury*; to the fifth, of *Jupiter*; to the sixth, of *Venus*; and to the seventh, of *Saturn*.

N°	The *Jewish* year.		Days
1	Tisri	— — Aug.—Sept.	30
2	Marchesvan	— — Sept.—Oct.	29
3	Casleau	— — Oct.—Nov.	30
4	Tebeth	— — Nov.—Dec.	29
5	Shebat	— — Dec.—Jan.	30
6	Adar	— — Jan.—Feb.	29
7	Nisan *or* Abib	— Feb.—Mar.	30
8	Jiar	— — Mar.—Apr.	29
9	Sivan	— — Apr.—May	30
10	Tamuz	— — May—June	29
11	Ab	— — June—July	30
12	Elul	— — July—Aug.	29
	Days in the year —	—	354

In the *embolimic* year after *Adar* they added a month called *Ve-Adar*, of 30 days.

N°	The *Egyptian* year.			Days
1	Thoth — —	August	29	30
2	Paophi — —	September	28	30
3	Athir — —	October	28	30
4	Chojac — —	November	27	30
5	Tybi — —	December	27	30
6	Mechir — —	January	26	30
7	Phamenoth— —	February	25	30
8	Parmuthi — —	March	27	30
9	Pachon — —	April	26	30
10	Payni — —	May	26	30
11	Epiphi — —	June	25	30
12	Mesori — —	July	25	30
	Epagomenæ or days added —			5
	Days in the year. —			365

N°	The *Arabic* and *Turkish* year.			Days
1	Muharram — —	July	16	30
2	Saphar — —	August	15	29
3	Rabia I. — —	September	13	30
4	Rabia II. — —	October	13	29
5	Jomada I. — —	November	11	30
6	Jomada II. — —	December	11	29
7	Rajab — —	January	9	30
8	Shasban — —	February	8	29
9	Ramadam — —	March	9	30
10	Shawal — —	April	8	29
11	Dulhaadah— —	May	7	30
12	Dulheggia— —	June	5	29
	Days in the year — —			354

The *Arabians* add 11 days at the end of every year, which keep the same months to the same seasons.

N°	The ancient *Grecian* year.		Days
1	Hecatombæon — —	June—July	30
2	Metagitnion — —	July—Aug.	29
3	Boedromion — —	Aug.—Sept.	30
4	Pyanepsion — —	Sept.—Oct.	29
5	Maimacterion — —	Oct.—Nov.	30
6	Posideon — —	Nov.—Dec.	29
7	Gamelion — —	Dec.—Jan.	30
8	Anthesterion — —	Jan.—Feb.	29
9	Elaphebolion — —	Feb.—Mar.	30
10	Municheon — —	Mar.—Apr.	29
11	Thargelion — —	Apr.—May	30
12	Schirrophorion —	May—June	29
	Days in the year	—	354

Days. 380. A *day* is either *natural* or *artificial.* The natural day contains 24 hours; the artificial, the time from Sun-rise to Sun-set. The natural day is either *astronomical* or *civil.* The astronomical day begins at noon, because the increase and decrease of days terminated by the horizon are very unequal among themselves; which inequality is likewise augmented by the inconstancy of the horizontal refractions, § 183; and therefore the astronomer takes the meridian for the limit of diurnal revolutions; reckoning noon, that is, the instant when the Sun's centre is on the meridian, for the beginning of the day. The *British*, *French*, *Dutch*, *Germans*, *Spaniards*, *Portuguese*, and *Egyptians*, begin the civil day at midnight: the ancient *Greeks*, *Jews*, *Bohemians*, *Silesians*, with the modern *Italians* and *Chinese*, begin it at Sun-setting: and the ancient *Babylonians*, *Persians*, *Syrians*, with the modern *Greeks*, at Sun-rising.

Hours. 381. An *hour* is a certain determinate part of the day, and is either equal or unequal. An equal hour is the 24th part of a mean natural day, as shewn by

well-regulated clocks or watches; but these hours are not quite equal as measured by the returns of the Sun to the meridian, because of the obliquity of the ecliptic, and Sun's unequal motion in it, § 224—245. Unequal hours are those by which the artificial day is divided into twelve parts, and the night into as many.

382. An hour is divided into 60 equal parts called *minutes*, a minute into 60 equal parts called *seconds*, and these again into 60 equal parts called *thirds*. The *Jews*, *Chaldeans*, and *Arabians*, divide the hour into 1080 equal parts called *scruples*; which number contains 18 times 60, so that one minute contains 18 scruples. Minutes, seconds, thirds, and scruples.

383. A *cycle* is a perpetual round, or circulation of the same parts of time of any sort. The *cycle of the Sun* is a revolution of 28 years, in which time the days of the month return again to the same days of the week; the Sun's place to the same signs and degrees of the ecliptic on the same months and days, so as not to differ one degree in 100 years; and the leap-years begin the same course over again with respect to the days of the week on which the days of the months fall. The *cycle of the Moon*, commonly called the *golden number*, is a revolution of 19 years; in which time, the conjunctions, oppositions, and other aspects of the Moon, are within an hour and half of being the same as they were on the same days of the months 19 years before. The *Indiction* is a revolution of 15 years, used only by the *Romans* for indicating the times of certain payments made by the subjects to the republic: it was established by *Constantine*, A. D. 312. Cycles of the Sun, Moon, and Indiction.

384. The year of our SAVIOUR'S birth, according to the vulgar æra, was the 9th year of the solar cycle; the first year of the lunar cycle; and the 312th year after his birth was the first year of the *Roman* indiction. Therefore to find the year of the solar cycle, add 9 to any given year of CHRIST, and divide the sum by 28, the quotient is the number of cycles To find the years of these cycles.

elapsed since his birth, and the remainder is the cycle for the given year: if nothing remain, the cycle is 28. To find the lunar cycle, add 1 to the given year of CHRIST, and divide the sum by 19; the quotient is the number of cycles elapsed in the interval, and the remainder is the cycle for the given year: if nothing remain, the cycle is 19. Lastly, subtract 312 from the given year of CHRIST, and divide the remainder by 15; and what remains after this division is the indiction for the given year: if nothing remain, the indiction is 15.

The deficiency of the lunar cycle, and consequence thereof.

385. Although the above deficiency in the lunar cycle of an hour and half every 19 years be but small, yet in time it becomes so sensible as to make a whole natural day in 310 years. So that, although this cycle be of use, when the golden numbers are rightly placed against the days of the months in the calendar, as in our *Common Prayer Books*, for finding the days of the mean conjunctions or oppositions of the Sun and Moon, and consequently the time of *Easter*; it will only serve for 310 years, *old style*. For as the new and full Moons anticipate a day in that time, the golden numbers ought to be placed one day earlier in the calendar for the next 310 years to come. These numbers were rightly placed against the days of new Moon in the calendar, by the council of *Nice*, A. D. 325; but the anticipation, which has been neglected ever since, is now grown almost into 5 days; and therefore all the golden numbers ought now to be placed 5 days higher in the calendar for the *old style* than they were at the time of the said council; or six days lower for the *new style*, because at present it differs 11 days from the *old*.

How to find the day of the new Moon by the golden number.

386. In the annexed table, the golden numbers under the months stand against the days of new Moon in the left-hand column, for the *new style*; adapted chiefly to the second year after leap-year, as being the nearest mean for all the four; and will serve till the year 1900. Therefore, to find the day of new

Days.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	9		9	17	17	6				11		19
2	.	17			6	14	14	3	11		19	
3	17	6	17	6			3	11		19	8	8
4	6		6	14	14	3			19	8		16
5		14			3	11	11	19	8		16	
6	14	3	14	3			19		.	16	5	5
7	3		3	11	11	19		8	16			13
8		11			19	8	8	16	5	5	13	
9	11	19	11	19						13		2
10			19	8	8	16	16	5	13		2	10
11	19	8					5	13	2	2	10	
12	8	10	8	16	16	5				10		18
13					5	13	13	2	10		18	7
14	16	5	16	5			2	10	18	18	7	
15	5		5	13	13	2				7		15
16		13			2	10	10	18	7		15	
17	18	2	13	2			18	7		15	4	4
18	2		2	10	10	18			15			12
19		10			18	7	7	15	4	4	12	
20	10	18	10	18			15			12	1	1
21	18		18	7	7	15		4	12			9
22		7		15	15	4	4	12	1	1	9	
23	7	15	7				12			9	17	17
24			15	4	4	12		1	9			6
25	15	4			12		1	9	17	17	6	
26	4		4	12		1				6		14
27		12		1	1	9	9	17	6		14	
28	12	1	12		9	.	17	6	14	14	3	3
29	1		1	9		17				3		11
30					17	6	6	14	3		11	
31	9		9				14	3		11		19

Moon in any month of a given year till that time, look for the golden number of that year under the desired month, and against it, you have the day of new Moon, in the left-hand column. Thus, suppose it were required to find the day of new Moon in *September* 1757; the golden number for that year is 10, which I look for under *September*, and right against it in the left-hand column I find 13, which is the day of new Moon in that month. *N. B.* If all the golden numbers, except 17 and 6, were set one day lower in the table, it would serve from the beginning of the year 1900 till the end of the year 2199. The first table after this chapter shews the golden number for 4000 years after the birth of CHRIST; by looking for the even hundreds of any given year at the left hand, and for the rest to make up that year at the head of the table; and where the columns meet, you have the golden number (which is the same both in *old* and *new style*) for the given year. Thus, suppose the golden number was wanted for the year 1757; I look for 1700 at the left hand of the table, and for 57 at the top of it; then guiding my eye downward from 57 to over against 1700, I find 10, which is the golden number for that year.

A perpetual table of the time of new Moon to the nearest hour for the *old style.*

387. But because the lunar cycle of 19 years sometimes includes five leap-years, and at other times only four, this table will sometimes vary a day from the truth in leap-years after *February*. And it is impossible to have one more correct, unless we extend it to four times 19 or 76 years; in which there are 19 leap-years without a remainder. But even then to have it of perpetual use, it must be adapted to the *old style;* because in every centurial year not divisible by 4, the regular course of leap-years is interrupted in the *new;* as will be the case in the year 1800. Therefore, upon the regular *old style* plan, I have computed the following table of the mean times of all the new Moons to the nearest hour for 76 years;

beginning with the year of CHRIST 1724, and ending with the year 1800.

This table may be made perpetual, by deducting 6 hours from the time of new Moon in any given year and month from 1724 to 1800, in order to have the mean time of new Moon in any year and month 76 years afterward; or deducting 12 hours for 152 years, 18 hours for 228 years, and 24 hours for 304 years: because in that time the changes of the Moon anticipate almost a complete natural day. And if the like number of hours be added for so many years past, we shall have the mean time of any new Moon already elapsed. Suppose, for example, the mean time of change was required for *January*, 1802; deduct 76 years, and there remains 1726, against which, in the following table, under *January*, I find the time of new Moon was on the 21st day, at 11 in the evening; from which take 6 hours, and there remains the 21st day, at 5 in the evening, for the mean time of change in *January* 1802. Or, if the time be required for *May*, A. D. 1701, add 76 years, and it makes 1777, which I look for in the table, and against it, under *May*, I find the new Moon in that year falls on the 25th day, at 9 in the evening; to which add 6 hours, and it gives the 26th day, at 3 in the morning, for the time of new Moon in *May*, A. D, 1701. By this addition for time past, or subtraction for time to come, the table will not vary 24 hours from the truth in less than 14592 years. And if, instead of 6 hours for every 76 years, we add or subtract only 5 hours 52 minutes, it will not vary a day in 10 millions of years.

Although this table is calculated for 76 years only, and according to the *old style*, yet by means of two easy equations it may be made to answer as exactly to the *new style*, for any time to come. Thus, because the year 1724 in this table is the first year of the cycle for which it is made; if from any year of

CHRIST after 1800 you subtract 1723, and divide the overplus by 76, the quotient will shew how many entire cycles of 76 years are elapsed since the beginning of the cycles here provided for; and the remainder will shew the year of the current cycle answering to the given year of CHRIST. Hence, if the remainder be 0, you must instead thereof put 76, and lessen the quotient by unity.

Then, look in the left-hand column of the table for the number in your remainder, and against it you will find the times of all the mean new Moons in that year of the present cycle. And whereas in 76 *Julian* years the Moon anticipates 5 hours 52 minutes, if therefore these 5 hours 52 minutes be multiplied by the above-found quotient, that is, by the number of entire cycles past; the product subtracted from the times in the table will leave the corrected times of the new Moons to the *old style;* which may be reduced to the *new style* thus:

Divide the number of entire hundreds in the given year of CHRIST by 4, multiply this quotient by 3, to the product add the remainder, and from their sum subtract 2: this last remainder denotes the number of days to be added to the times above corrected, in order to reduce them to the *new style*. The reason of this is, that every 400 years of the *new style* gains 3 days upon the *old style:* one of which it gains in each of the centurial years succeeding that which is exactly divisible by 4 without a remainder; but then, when you have found the days so gained, 2 must be subtracted from their number on account of the rectifications made in the calendar by the council of *Nice*, and since by pope *Gregory*. It must also be observed, that the additional days found as above-directed, do not take place in the centurial years which are not multiples of 4 till *February* 29th *old style*, for on that day begins the difference between the *styles;* till which day, there-

fore, those that were added in the preceding years must be used. The following example will make this accommodation plain.

Required the mean time of new Moon in June, A. D. 1909 *N. S.*

From 1909 take 1723 years, and there remains	186
Which divided by 76, gives the quotient 2 and the remainder . . .	34
Then against 34 in the table is *June*	$5^d\ 8^h\ 0^m$ afternoon.
And $5^h\ 52^m$ multiplied by 2 make to be subtr. .	11 44
Remains the mean time according to the *old style*, *June*	$5^d\ 8^h\ 16^m$
Entire hundreds in 1909 are 19, which divide by 4, quotes	4
And leaves a remainder of	3
Which quotient multiplied by 3 makes 12, and the remainder added makes	15
From which subtract 2, and there remains . . .	13
Which number of days added to the above time, *old style*, gives *June* . .	$18^d\ 8^h\ 16^m$ morn. *N. S.*

So the mean time of new Moon in *June* 1909, *new style*, is the 18th day, at 16 minutes past 8 in the morning.

If 11 days be added to the time of any new Moon in this table, it will give the time of that new Moon according to the *new style* till the year 1800. And if 14 days 18 hours 22 minutes be added to the mean time of new Moon in either *style*, it will give the mean time of the next full Moon according to that *style*.

A TABLE *shewing the Times of all the mean Changes of the Moon, to the nearest Hour, through four Lunar Periods, or 76 Years.* M *Signifies Morning;* A *Afternoon.*

Years of the Cyc.	A.D.	January D.	January H.	February D.	February H.	March D.	March H.	April D.	April H.
1	1724	14	5 A	13	5 M	13	6 A	[redacted]	7 M
2	1725	3	2 M	1	2 A	[redacted]	3 M	[redacted]	4 A
3	1726	21	11 A	20	11 M	21	12 A	20	1 A
4	1727	11	8 M	9	9 A	11	9 M	9	10 A
5	1728	30	6 M	28	7 A	29	7 M	27	8 A
6	1729	[redacted]	2 A	17	3 M	[redacted]	4 A	17	4 M
7	1730	[redacted]	11 A	6	0 A	[redacted]	1 M	6	1 A
8	1731	26	9 A	25	10 M	26	10 A	15	11 M
9	1732	16	5 M	14	6 A	15	7 M	23	8 A
10	1733	4	2 A	3	3 M	[redacted]	4 A	3	4 M
11	1734	23	0 A	22	1 M	23	1 A	22	2 M
12	1735	12	9 A	11	[redacted]	12	10 A	11	11 M
13	1736	2 31	5 M 6 A	—		1 [redacted]	7 M 8 A	29	9 M
14	1737	20	3 M	18	4 A	[redacted]	4 M	18	5 A
15	1738	9	11 M	7	12 A	9	1 A	[redacted]	1 M
16	1739	[redacted]	9 M	26	10 A	28	1 M	26	12 A
17	1740	17	6 A	[redacted]	7 M	16	8 A	15	9 M
18	1741	6	[redacted]	4	4 A	6	4 M	4	5 A
19	1742	[redacted]	12 A	23	1 A	[redacted]	2 M	23	3 A
20	1743	14	[redacted]	12	10 A	14	11 M	12	12 A
21	1744	3	6 A	2	7 M	2	8 A	1 30	9 M 9 A
22	1745	21	4 A	20	[redacted]	21	5 A	20	6 M
23	1746	10	12 A	9	1 A	11	2 M	9	3 A
24	1747	29	10 A	28	11 M	29	11 A	28	0 A
25	1748	19	6 M	17	7 A	[redacted]	8 M	16	9 A
26	1749	7	3 A	6	4 M	7	5 A	6	6 M

A TABLE *of the mean New Moons*, &c.

Yrs. of the Cyc.	A. D.	*May* D.	*May* H.	*June* D.	*June* H.	*July* D.	*July* H.	*August* D.	*August* H.
1	1724	11	8 A	10	8M	9	9 A	8	10M
2	1725	1 30	4M 5 A	29	6M	28	7 A	27	8M
3	1726	20	1M	18	2 A	18	3M	16	4 A
4	1727	9	11M	7	12 A	7	0 A	6	1M
5	1728	27	8M	25	9 A	25	10M	23	11 A
6	1729	16	5 A	15	6M	14	7 A	12	7M
7	1730	6	2M	4	3 A	4	3M	2	4 A
8	1731	24	11 A	23	0 A	23	1M	21	2 A
9	1732	13	8M	11	9 A	11	10M	9	11 A
10	1733	2	5 A	1 30	6M 7 A	30	8M	28	8 A
11	1734	21	2 A	20	3M	19	4 A	18	5M
12	1735	10	11 A	9	0 A	9	1M	7	2 A
13	1736	28	9 A	27	10M	26	11 A	25	0 A
14	1737	18	5M	16	6 A	16	7M	14	8 A
15	1738	7	2 A	6	3 A	5	4 A	4	5M
16	1739	26	0 A	25	1M	24	2 A	23	3M
17	1740	14	9 A	13	10M	12	11 A	11	0 A
18	1741	4	5M	2	6 A	2 31	7M 7 A	30	8M
19	1742	23	3M	21	4 A	21	5M	19	6 A
20	1743	12	0 A	11	1M	10	2 A	9	3M
21	1744	30	10M	28	11 A	28	0 A	26	12 A
22	1745	19	6 A	18	7M	17	8 A	16	8M
23	1746	9	3M	7	4 A	7	5M	5	6 A
24	1747	27	12 A	26	1 A	26	2M	24	3 A
25	1748	16	9M	14	10 A	14	11M	12	12 A
26	1749	5	6 A	4	7M	3	8 A	2 31	9M 9 A

A TABLE *of the mean New Moons, &c.*

Yrs. of the Cyc.	A.D.	*Sept.* D.	*Sept.* H.	*October* D.	*October* H.	*Nov.* D.	*Nov.* H.	*Dec.* D.	*Dec.* H.
1	1724	6	10 A	6	11M	4	12 A	4	1 A
2	1725	25	8 A	25	9M	23	10 A	23	11M
3	1726	15	5M	14	5 A	13	6M	12	7 A
4	1727	4	1 A	4	2M	2	3 A	2 31	4M 5 A
5	1728	22	11M	21	12 A	20	1 A	20	2M
6	1729	11	8 A	11	9M	9	10 A	9	11M
7	1730	2 30	5M 6 A	30	7M	28	8 A	28	9M
8	1731	20	2M	19	3 A	18	4M	17	5 A
9	1732	8	11M	7	12 A	6	1 A	6	2M
10	1733	27	9M	26	10 A	25	11M	24	11 A
11	1734	16	5 A	16	6M	14	7 A	14	8M
12	1735	6	2M	5	3 A	4	4M	3	5 A
13	1736	23	12 A	23	1 A	22	2M	21	3 A
14	1737	13	8M	12	9 A	11	10M	10	11 A
15	1738	2	5 A	2 31	6M 7 A	30	8M	29	8 A
16	1739	21	3 A	21	4M	19	5 A	19	6M
17	1740	9	12 A	9	1 A	8	2M	7	3 A
18	1741	28	9 A	28	10M	26	11 A	26	11M
19	1742	18	6M	17	7 A	16	8M	15	9 A
20	1743	7	3 A	7	4M	5	5 A	5	6M
21	1744	25	1 A	25	2M	23	3 A	23	3M
22	1745	14	9 A	14	10M	12	11 A	12	0 A
23	1746	4	6M	3	7 A	2	8M	1 31	9 A 10M
24	1747	23	3M	22	4 A	21	5M	20	6 A
25	1748	11	0 A	11	1M	9	2 A	9	3M
26	1749	30	10M	29	11 A	28	0 A	27	12 A

A TABLE *of the mean New Moons continued.*

Yrs. of the Cyc	A.D.	*January* D.	H.	*Feb.* D.	H.	*March* D.	H.	*April* D.	H.
27	1750	26	1 A	25	2M	26	3 A	25	4M
28	1751	15	10 A	14	11M	15	11 A	14	0 A
29	1752	5	6M	3	7 A	4	[illegible]	2	9 A
30	1753	23	4M	21	5 A	23	6M	21	7 A
31	1754	12	1 A	11	2M	12	3 A	11	4M
32	1755	1 31	10 A 11M			1 31	11 A 0 A	29	12 A
33	1756	20	7 A	19	8M	19	9 A	18	9M
34	1757	9	4M	7	5 A	[illegible]	6M	[illegible]	7 A
35	1758	28	2M	26	3 A	28	3M	26	4 A
36	1759	17	10M	15	11 A	17	0 A	16	1M
37	1760	6	7 A	5	8M	5	9 A	4	10M
38	1761	24	5 A	23	6M	24	7 A	23	8M
39	1762	14	2M	12	3 A	14	3M	12	4 A
40	1763	3	11M	1	12 A	[illegible]	0 A	2	1M
41	1764	22	8M	20	9 A	21	10M	19	11 A
42	1765	10	5 A	[illegible]	6M	10	6 A	9	7M
43	1766	29	2 A	28	3 A	29	4 A	28	5M
44	1767	18	11 A	17	12 A	19	1M	17	2 A
45	1768	[illegible]	8M	6	9 A	7	10M	[illegible]	11 A
46	1769	26	6M	24	7 A	26	7M	24	8 A
47	1770	15	2 A	14	3M	15	4 A	14	5M
48	1771	4	11M	3	0 A	[illegible]	1M	3	2 A
49	1772	23	9 A	22	10M	22	10 A	21	11M
50	1773	12	5M	10	6 A	12	7M	10	8 A
51	1774	1 31	2 A 3M			1 31	4 A 5M	29	5 A
52	1775	20	0 A	19	1M	20	2 A	19	3M
53	1776	9	9 A	[illegible]	10M	[illegible]	10 A	7	11M

A TABLE *of the New Moons continued.*

Yrs. of the Cyc.	A.D.	May D.	May H.	June D.	June H.	July D.	July H.	August D.	August H.
27	1750	24	4 A	23	5M	[illegible]	6 A	21	7M
28	1751	13	12 A	[illegible]	1 A	12	2M	10	3 A
29	1752	2 31	9M 10 A	30	11M	29	12 A	28	0 A
30	1753	21	7M	19	8M	19	9M	17	10 A
31	1754	10	4 A	9	5M	8	6 A	7	7M
32	1755	29	1 A	28	2M	27	3 A	25	3M
33	1756	17	10 A	16	11M	15	12 A	14	1 A
34	1757	7	7M	5	8 A	5	9M	3	10 A
35	1758	26	4M	24	5 A	24	6M	22	7 A
36	1759	15	1 A	14	2M	13	3 A	[illegible]	2M
37	1760	3	10 A	2	11M	1 31	12 A 1 A	30	1M
38	1761	22	9 A	21	10M	20	10 A	19	11M
39	1762	12	4M	10	5 A	10	6M	8	7 A
40	1763	1 31	1 A 2M	29	3 A	29	4M	27	4 A
41	1764	19	11M	17	12 A	17	1 A	16	[illegible]
42	1765	8	7 A	7	8M	6	9 A	5	10M
43	1766	27	5 A	26	6M	25	7 A	24	8M
44	1767	17	2M	15	3 A	15	4M	13	5 A
45	1768	[illegible]	11M	3	12 A	[illegible]	1 A	2 31	2M 2 A
46	1769	24	8M	22	9 A	[illegible]	10M	20	11 A
47	1770	13	5 A	12	4M	11	7 A	10	8M
48	1771	3	2M	1	3 A	1 30	4M 5 A	29	[illegible]
49	1772	20	11 A	19	0 A	19	1M	17	2 A
50	1773	10	8M	8	9 A	8	9M	6	10 A
51	1774	[illegible]	6M	27	7 A	27	8M	25	8 A
52	1775	18	3 A	17	4M	16	5 A	15	6M
53	1776	6	12 A	5	0 A	5	1M	3	2 A

A TABLE *of the mean New Moons continued.*

Yrs of the Cyc.	A.D.	*Sept.*		*October*		*Nov.*		*Dec.*	
		D.	H.	D.	H.	D.	H.	D.	H.
27	1750	19	7 A	19	8M	17	9 A	17	10M
28	1751	9	3M	8	4 A	7	5M	6	6 A
29	1752	27	1M	26	2 A	25	3M	24	3 A
30	1753	16	10M	15	11 A	14	0 A	14	1M
31	1754	5	7 A	5	8M	3	9 A	3	10M
32	1755	24	4 A	24	5M	22	6 A	22	6M
33	1756	13	1M	13	2 A	11	3M	10	4 A
34	1757	2	10M	1 31	11 A 0 A	30	1M	29	1 A
35	1758	21	7M	20	8 A	19	9M	18	10 A
36	1759	10	4 A	10	5M	8	6 A	8	7M
37	1760	28	2 A	28	3M	26	4 A	26	4M
38	1761	17	11 A	17	0 A	16	1M	15	2 A
39	1762	6	7M	6	8 A	5	9M	4	10 A
40	1763	26	5M	25	6 A	24	7M	28	7 A
41	1764	14	2 A	14	3M	13	4 A	12	5M
42	1765	3	10 A	3	11M	1	12 A	1 31	1 A 1M
43	1766	22	8 A	22	9M	20	10 A	20	11M
44	1767	12	6M	11	6 A	10	7M	9	8M
45	1768	30	3M	29	4 A	28	5M	27	5 A
46	1769	19	1M	18	12 A	17	1 A	17	2M
47	1770	8	8 A	8	9M	6	10 A	6	11M
48	1771	27	6 A	27	7M	25	8 A	25	9M
49	1772	16	2M	15	3 A	14	4M	13	5 A
50	1773	5	11M	4	12 A	3	1 A	3	2M
51	1774	24	9M	23	10 A	22	11M	21	11 A
52	1775	13	6 A	13	7M	11	8 A	11	9M
53	1776	32	2M	1 1	3 A 4M	29	5 A	29	5M

Yrs. of the Cyc.	A.D.	*January* D.	*January* H.	*February* D.	*February* H.	*March* D.	*March* H.	*April* D.	*April* H.
54	1777	27	6 A	26	7 M	27	8 A	26	9 M
55	1778	17	3 M	15	4 A	17	5 M	15	6 A
56	1779	6	0 A	5	1 M	6	2 A	5	3 M
57	1780	25	10 M	23	11 A	24	11 M	22	12 A
58	1781	13	6 A	12	7 M	13	8 A	12	9 M
59	1782	2	3 M	1	4 A	3	5 M	1	6 A
60	1783	22	1 M	20	2 A	22	2 M	20	3 A
61	1784	11	9 M	9	10 A	10	11 M	8	12 A
62	1785	29	7 M	27	8 A	29	9 M	27	10 A
63	1786	18	4 A	17	5 M	18	5 A	17	6 M
64	1787	7	12 A	6	1 A	8	2 M	6	3 A
65	1788	26	10 A	25	11 M	25	12 A	24	1 A
66	1789	15	7 M	13	8 A	15	9 M	13	10 A
67	1790	4	4 A	3	5 M	4	5 A	3	6 M
68	1791	23	1 A	22	2 M	23	3 A	22	4 M
69	1792	12	10 A	11	11 M	11	12 A	10	1 A
70	1793	1 30	7 M 8 A			1 30	9 M 10 A	29	10 M
71	1794	20	5 M	18	6 A	20	6 M	18	7 A
72	1795	9	1 A	8	2 M	9	3 A	8	4 M
73	1796	28	11 M	26	12 A	27	0 A	26	1 M
74	1797	16	7 A	15	8 M	16	9 A	15	10 M
75	1798	6	4 M	4	5 A	6	6 M	4	7 A
76	1799	25	2 M	23	3 A	25	4 M	23	5 A
*1	1800	14	11 M	12	12 A	13	0 A	12	1 M

A Table of the mean New Moons concluded.

* The year 1800 begins a new cycle.

A Table *of the mean New Moons concluded.*

Yrs. of the Cyc.	A.D.	*May*		*June*		*July*		*August*	
		D.	H.	D.	H	D.	H.	D.	H.
54	1777	25	9 A	24	10M	23	11 A	22	0 A
55	1778	15	6M	13	7 A	13	8M	11	9 A
56	1779	4	3 A	3	4M	2	5 A	1 30	6M 6 A
57	1780	22	0 A	21	1M	20	2 A	19	3 A
58	1781	11	9 A	10	10M	9	11 A	8	0M
59	1782	1 30	6M 7 A	29	8M	28	9 A	27	9M
60	1783	20	3M	18	4 A	18	5M	16	6 A
61	1784	8	0 A	7	1M	6	2 A	5	3M
62	1785	27	10M	25	11 A	25	0 A	24	1M
63	1786	15	6 A	15	7M	14	8 A	13	9M
64	1787	6	3M	4	4 A	4	5M	2	6 A
65	1788	24	1M	22	2 A	22	3M	20	4 A
66	1789	13	10M	11	11 A	11	0 A	10	1M
67	1790	2	6 A	1 30	7M 8 A	30	9M	28	9 A
68	1791	21	4 A	20	5M	19	6 A	18	7M
69	1792	10	1M	8	2 A	8	3M	6	4 A
70	1793	28	11 A	27	0 A	27	1M	25	1 A
71	1794	18	7M	16	8 A	16	9M	14	10 A
72	1795	7	4 A	6	5M	5	6 A	4	7M
73	1796	25	1 A	24	2M	23	3 A	22	4M
74	1797	14	10 A	13	11M	12	12 A	11	1 A
75	1798	4	7M	2	8 A	2 31	9M 10 A	30	10M
76	1799	23	5M	21	6 A	21	6M	19	8 A
1	1800	11	1 A	10	2M	9	3 A	8	4M

A TABLE *of the mean New Moons concluded.*

Yrs. of the Cyc.	A.D.	*September* D.	H.	*October* D.	H.	*November* D.	H.	*Dec.* D.	H.
54	1777	20	12A	10	1 A	19	2M	18	3 A
55	1778	10	9M	9	10 A	8	11M	7	12 A
56	1779	29	7M	28	8 A	27	9M	26	9 A
57	1780	17	3A	17	4M	15	5 A	15	6M
58	1781	6	12 A	6	1 A	5	2M	4	3 A
59	1782	25	10 A	25	11M	23	12 A	23	0 A
60	1783	15	6M	14	7 A	13	8M	12	9 A
61	1784	3	3 A	3	4M	1	5 A	1 30	6M 6 A
62	1785	22	1 A	22	2M	20	3 A	20	3M
63	1786	11	9 A	11	10M	9	11 A	9	0 A
64	1787	1 30	6M 7 A	30	8M	28	9 A	28	9M
65	1788	19	4M	18	5 A	17	6M	16	7 A
66	1789	8	1 A	8	2M	6	3 A	6	4M
67	1790	29	10M	26	11 A	25	0 A	24	12 A
68	1791	16	7 A	16	8M	14	9 A	14	10M
69	1792	5	4 A	4	5 A	3	6M	2	7 A
70	1793	24	2M	23	3 A	22	4M	21	4 A
71	1794	13	10M	12	11 A	11	0 A	11	1M
72	1795	2	7 A	2 31	8M 9 A	30	10M	29	10 A
73	1796	20	4 A	20	5M	18	6 A	18	7M
74	1797	0	1M	9	2 A	8	3M	7	4 A
75	1798	28	11 A	28	0 A	27	1M	26	1 A
76	1799	18	8M	17	9 A	16	10M	15	11 A
1	1800	6	4 A	6	5M	4	6 A	4	7M

Easter cycle deficient.

388. The *cycle of Easter*, also called the *Dionysian period*, is a revolution of 532 years, found by multiplying the solar cycle 28 by the lunar cycle 19. If the new Moons did not anticipate upon this cycle, *Easter-day* would always be the *Sunday* next after the first full Moon which follows the 21st of *March*.

But on account of the above anticipation, § 422. to which no proper regard was had before the late alteration of the *style*, the *ecclesiastic Easter* has several times been a week different from the *true Easter* within this last century: which inconvenience is now remedied by making the table which used to find *Easter for ever*, in the Common Prayer Book, of no longer use than the lunar difference from the *new style* will admit of.

Number of direction.

389. The *earliest Easter possible* is the 22d of *March*, the *latest* the 25th of *April*. Within these limits are 35 days, and the number belonging to each of them is called the *number of direction;* because thereby the time of Easter is found for any given year. To find the number of direction, according to the *new style*, enter Table V. following this chapter, with the complete hundreds of any given year at the top, and the years thereof (if any) below a hundred at the left hand; and where the columns meet is the Dominical letter for the given year. Then enter Table I. with the complete hundreds of the same year at the left hand, and the years below a hundred at the top; and where the columns meet is the golden number for the same year. Lastly, enter Table II. with the Dominical letter at the left hand, and golden number at the top; and where the columns meet is the number of direction for that year; which number added to the 21st day of *March*, shews on what day, either of *March* or *April*, *Easter-Sunday* falls in that year. Thus the Dominical letter *new style* for the year 1757 is *B*, (Table V.) and the golden number is 10, (Table I.) by which in Table II. the number of direction is

found to be 20; which reckoning from the 21st of *March*, ends on the 10th of *April, that is, Easter-Sunday*, in the year 1757. *N. B.* There are always two Dominical letters to the leap-year, the first of which takes place to the 24th of *February*, the last for the following part of the year. To find the true *Easter*.

390. *The first seven letters of the alphabet* are commonly placed in the annual almanacs, to shew on what days of the week the days of the months fall throughout the year. And because one of those seven letters must necessarily stand against *Sunday*, it is printed in a capital form, and called the *Dominical letter*: the other six being inserted in small characters, to denote the other six days of the week. Now, since a common *Julian year* contains 365 days, if this number be divided by 7 (the number of days in a week) there will remain one day. If there had been no remainder, it is plain the year would constantly begin on the same day of the week. But since 1 remains, it is as plain that the year must begin and end on the same day of the week; and therefore the next year will begin on the day following. Hence, when *January* begins on *Sunday*, *A* is the Dominical or *Sunday* letter for that year: then, because the next year begins on *Monday*, the *Sunday* will fall on the seventh day, to which is annexed the seventh letter *G*, which therefore will be the Dominical letter for all that year: and as the third year will begin on *Tuesday*, the *Sunday* will fall on the sixth day, therefore *F* will be the *Sunday* letter for that year. Whence it is evident, that the *Sunday* letters will go annually in a retrograde order thus, *G, F, E, D, C, B, A*. And in the course of seven years, if they were all common ones, the same days of the week and Dominical letters would return to the same days of the months. But because there are 366 days in a leap-year, if this number be divided by 7, there will remain two days over and above the 52 weeks of which the year consists. Dominical letter

And therefore, if the leap-year begins on *Sunday*, it will end on *Monday;* and the next year will begin on *Tuesday*, the first *Sunday* whereof must fall on the sixth of *January*, to which is annexed the letter *F*, and not *G*, as in common years. By this means, the leap-year returning every fourth year, the order of the Dominical letters is interrupted; and the series cannot return to its first state till after four times seven, or 28 years; and then the same days of the months return in order to the same days of the week as before.

To find the Dominical letter.

391. *To find the Dominical letter for any year either before or after the Christian æra.* In Table III. or IV. *for old style*, or V. for *new style*, look for the hundreds of years at the head of the table, and for the years below a hundred (to make up the given year) at the left hand; and where the columns meet, you have the Dominical letter for the year desired. Thus, suppose the Dominical letter be required for the year of CHRIST 1758, *new style*, I look for 1700 at the head of Table V. and for 58 at the left hand of the same table; and in the angle of meeting, I find *A*, which is the Dominical letter for that year. If it was wanting for the same year *old style*, it would be found by Table IV. to be *D*. But *to find the Dominical letter for any given year before* CHRIST, subtract one from *that* year, and then proceed in all respects as just now taught, to find it by Table III. Thus, suppose the Dominical letter be required for the 585th year before the first year of CHRIST, look for 500 at the head of Table III. and for 84 at the left hand; in the meeting of these columns you will find *FE*, which were the Dominical letters for that year, and shew that it was a leap-year; because leap-year has always two Dominical letters.

To find the day of the month.

392. *To find the day of the month answering to any day of the week, or the day of the week answering to any day of the month, for any year past*

or to come. Having found the Dominical letter for the given year, enter Table VI, with the Dominical letter at the head; and under it, all the days in that column are *Sundays*, in the divisions of the months; the next column to the right hand are *Mondays*, the next, *Tuesdays*; and so on, to the last column under *G*; from which go back to the column under *A*, and thence proceed toward the right hand as before. Thus, in the year 1757, the Dominical letter *new style* is *B*, in Table V; then, in Table VI, all the days under *B* are *Sundays* in that year, *viz.* the 2d, 9th, 16th, 23d, and 30th of *January* and *October*; the 6th, 13th, 20th, and 27th of *February*, *March*, and *November*; the 3d, 10th, and 17th of *April* and *July*, together with the 31st of *July*; and so on, to the foot of the column. Then, of course, all the days under *C* are *Mondays*, namely, the 3d, 10th, *&c.* of *January* and *October*; and so of all the rest in that column. If *the day of the week answering to any day of the month* be required, it is easily had from the same table by the letter that stands at the top of the column in which the given day of the month is found. Thus, the letter that stands over the 28th of May is *A*; and in the year 585 before CHRIST, the Dominical letters were found to be *F*, *E*, § 391; which being a leap-year, and *E* taking place from the 24th of *February* to the end of that year, shews, by the table, that the 25th of *May* was on a *Sunday*; and therefore the 28th must have been on a *Wednesday*; for when *E* stands for *Sunday*, *F* must stand for *Monday*, *G* for *Tuesday*, &c. Hence, as it is said that the famous eclipse of the Sun foretold by THALES, by which a peace was brought about between the *Medes* and *Lydians*, happened on the 28th of *May*, in the 585th year before CHRIST, it fell on a *Wednesday*.

393. From the multiplication of the solar cycle *Julian period*
of 28 years, into the lunar cycle of 19 years, and the Roman indiction of 15 years, arises the great *Julian*

period, consisting of 7980 years, which had its beginning 764 years before *Strauchius*'s supposed year of the creation (for no later could all the three cycles begin together), and it is not yet completed: and therefore it includes all other cycles, periods, and æras. There is but one year in the whole period that has the same numbers for the three cycles of which it is made up: and therefore, if historians had remarked in their writings the cycles of each year, there had been no dispute about the time of any action recorded by them.

To find the year of this period.

394. The *Dionysian* or vulgar æra of CHRIST's birth was about the end of the year of the *Julian* period 4713; and consequently the first year of his age, according to that account, was the 4714th year of the said period. Therefore, if to the current year of CHRIST we add 4713, the sum will be the year of the *Julian* period. So the year 1757 will be found to be the 6470th year of that period. Or, to find the year of the *Julian* period answering to any given year before the first year of CHRIST, subtract the number of that given year from 4714, and the remainder will be the *Julian* period. Thus, the year 585 before the first year of CHRIST (which was the 584th before his birth) was the 4129th year of the said period. Lastly, to find the cycles of the Sun, Moon, and indiction, for any given year of this period, divide the given year by 28, 19, and 15; the three remainders will be the cycles sought, and the quotients the numbers of cycles elapsed since the beginning of the period. So in the above 4714th year of the *Julian* period, the cycle of the Sun was 10, the cycle of the Moon 2, and the cycle of indiction 4; the solar cycle having run through 168 courses, the lunar 248, and the indiction 314.

And the cycles of that year.

The true æra of CHRIST's birth.

395. The vulgar æra of CHRIST's birth was never settled till the year 527, when *Dionysius Exiguus*, a *Roman* abbot, fixed it to the end of the 4713th year of the *Julian* period, which was four

years too late.—For our SAVIOUR was born before the death of *Herod*, who sought to kill him as soon as he heard of his birth. And according to the testimony of *Josephus* (B. xvii. ch. 8.) there was an eclipse of the Moon at the time of *Herod*'s last illness; which eclipse appears by our astronomical tables to have been in the year of the *Julian* period 4710, *March* 13th, at 3 hours past midnight, at *Jerusalem*. Now as our SAVIOUR must have been born some months before *Herod*'s death, since in the interval he was carried into *Egypt*, the latest time in which we can fix the true æra of his birth is about the end of the 4709th year of the *Julian* period.

There is a remarkable prophecy delivered to us in the ninth chapter of the book of *Daniel*, which, from a certain *epoch*, fixes the time of restoring the state of the *Jews*, and of building the walls of *Jerusalem*, the coming of the MESSIAH, his death, and the destruction of *Jerusalem*.—But some parts of this prophecy (*Ver.* 25.) are so injudiciously pointed in our *English* translation of the *Bible*, that, if they be read according to those stops of pointing, they are quite unintelligible.—But the learned Dr. *Prideaux*, by altering these stops, makes the sense very plain; and as he seems to me to have explained the whole of it better than any other author I have read on the subject, I shall set down the whole of the prophecy according as he has pointed it, to shew in what manner he has divided it into four different parts.

Ver. 24. *Seventy weeks are determined upon thy People, and upon thy holy City, to finish the Transgression, and to make an end of Sins, and to make reconciliation for Iniquity, and to bring in everlasting Righteousness, and to seal up the Vision, and the Prophecy, and to anoint the most holy. Ver.* 25, *Know therefore and understand, that from the going forth of the Commandment to restore and to build* Jerusalem *unto the* MESSIAH *the Prince shall be seven*

weeks and three-score and two weeks, the street shall be built again, and the wall even in troublous times. Ver. 26. *And after three-score and two weeks shall* MESSIAH *be cut off, but not for himself, and the people of the Prince that shall come, shall destroy the City and Sanctuary, and the end thereof shall be with a Flood, and unto the end of the war desolations are determined.* Ver. 27. *And he shall confirm the covenant with many for one week, and in the midst* of the week he shall cause the sacrifice and the oblation to cease, and for the overspreading of abominations he shall make it desolate even until the Consummation, and that determined shall be poured upon the desolate.*

This commandment was given to *Ezra* by *Artaxerxes Longimanus*, in the seventh year of that king's reign (*Ezra*, ch. vii. ver. 11—26). *Ezra* began the work, which was afterwards accomplished by *Nehemiah*: in which they met with great opposition and trouble from the *Samaritans* and others, during the first seven weeks, or 49 years.

From this accomplishment till the time when CHRIST's messenger, *John* the Baptist, began to preach the Kingdom of the MESSIAH, 62 weeks, or 434 years.

From thence to the beginning of CHRIST's public ministry, half a week, or $3\frac{1}{2}$ years.

And from thence to the death of CHRIST, half a week, or $3\frac{1}{2}$ years; in which half-week he preached, and *confirmed the covenant* of the Gospel with many.

In all, from the going forth of the commandment till the Death of CHRIST, 70 weeks, or 490 years.

And, lastly, in a very striking manner, the prophecy foretels what should come to pass after the expiration of the *seventy weeks*; namely, *the Destruction of the City and Sanctuary by the people of the Prince that was to come*; which were the *Roman*

* The Doctor says, that this ought to be rendered *the* [illegible] *part of the week*, not *the midst*.

armies, under the command of *Titus* their prince, who came upon *Jerusalem* as a torrent, with their idolatrous images, which were an abomination to the *Jews*, and under which they marched against them, invaded their land, and besieged their holy city, and by a calamitous war, brought such utter destruction upon both, that the *Jews* have never been able to recover themselves, even to this day.

Now, both by the undoubted canon of *Ptolemy*, and the famous *æra of Nabonassar*, the beginning of the seventh year of the reign of *Artaxerxes Longimanus*, king of *Persia*, (who is called *Ahasuerus* in the book of *Esther*,) is pinned down to the 4256th year of the *Julian* period, in which year he gave *Ezra* the above-mentioned ample commission: from which, count 490 years to the death of CHRIST, and it will carry the same to the 4746th year of the *Julian* period.

Our *Saturday* is the *Jewish* Sabbath: and it is plain from St. *Mark*, ch. xv. ver. 42, and St. *Luke*, ch. xxiii. ver. 54, that CHRIST was crucified on a *Friday*, seeing the crucifixion was on the day next before the *Jewish* Sabbath.—And according to St. *John*, ch. xviii. ver. 28, on the day that the Passover was to be eaten, at least by many of the *Jews*.

The *Jews* reckoned their months by the Moon, and their years by the apparent revolution of the Sun: and they ate the Passover on the 14th day of the month of *Nisan*, which was the first month of their year, reckoning from the first appearance of the new Moon, which at that time of the year might be on the evening of the day next after the change, if the sky was clear. So that their 14th day of the month answers to our fifteenth day of the Moon, on which she is full.—Consequently, the Passover was always kept on the day of full Moon.

And the full Moon at which it was kept, was *that* one which happened next after the vernal equinox. —For *Josephus* expressly says (*Antiq*. B. iii. ch. 10.)

"The Passover was kept on the 14th day of the "month of *Nisan*, according to the Moon, when the "Sun was in *Aries*."—And the Sun always enters *Aries* at the instant of the vernal equinox; which, in our Saviour's time, fell on the 22d day of *March*.

The dispute among chronologers about the year of CHRIST's death is limited to four or five years at most.—But, as we have shewn that he was crucified on the day of a Pascal full Moon, and on a *Friday*, all that we have to do, in order to ascertain the year of his death, is only to compute in which of those years there was a Passover full Moon on a *Friday*.—For, the full Moons anticipate eleven days every year (12 lunar months being so much short of a solar year), and therefore, once in every three years at least, the Jews were obliged to set their Passover a whole month forwarder than it fell by the course of the Moon, on the year next before, in order to keep it at the full Moon next after the equinox; therefore there could not be two Passovers on the same nominal day of the week within the compass of a few neighbouring years. And I find by calculation, the *only* Passover full Moon that fell on a *Friday*, for several years before or after the disputed year of the crucifixion, was on the 3d day of *April*, in the 4746th year of the *Julian* period, which was the 490th year after *Ezra* received the above-mentioned commission from *Artaxerxes Longimanus*, according to *Ptolemy's* canon, and the year in which the MESSIAH was to be cut off, according to the prophecy, reckoning from the going forth of *that* commission or commandment: and this 490th year was the 33d year of our SAVIOUR's age, reckoning from the vulgar æra of his birth; but the 37th, reckoning from the true æra thereof.

And, when we reflect on what the *Jews* told him, some time before his death (*John* viii. 57.) "*thou* "*art not yet fifty years old*," we must confess that it should seem much likelier to have been said to a

person near forty than to one but just turned of thirty. And we may easily suppose that St. *Luke* expressed himself only in round numbers, when he said that *Christ was baptized about the 30th year of his age*, when he began his public ministry; as our SAVIOUR himself did, when he said he should lie *three days and three nights in the grave.*

The 4746th year of the *Julian* period, which we have astronomically proved to be the year of the crucifixion, was the 4th year of the 202d Olympiad; in which year, *Phlegon*, a heathen writer, tells us, *there was the most extraordinary eclipse of the Sun that ever was seen.* But I find by calculation, that there could be no total eclipse of the Sun at *Jerusalem*, in a natural way, in that year.—So that what *Phlegon* here calls an eclipse of the Sun seems to have been the great darkness for three hours at the time of our SAVIOUR's crucifixion, as mentioned by the Evangelists: a darkness altogether supernatural, as the Moon was then in the side of the heavens opposite to the Sun; and therefore could not possibly darken the Sun to any part of the Earth.

396. As there are certain fixed points in the heavens from which astronomers begin their computations, so there are certain points of time from which historians begin to reckon; and these points, or roots of time, are called *æras* or *epochs*. The most remarkable *æras* are, those of the *creation*, the *Greek Olympiads*, the building of *Rome*, the *æra* of *Nabonassar*, the death of *Alexander*, the birth of CHRIST, the *Arabian Hegira*, and the *Persian Yesdegird*: all which, together with several others of less note, have their beginnings in the following table fixed to the years of the *Julian period*, to the age of the world at those times, and to the years before and after the year of CHRIST's birth.

A Table of remarkable Æras and Events.

	Julian Period.	Y. of the World.	Before Christ.
1. The Creation of the World	706	0	4007
2. The Deluge, or *Noah*'s Flood	2362	1656	2351
3. The *Assyrian* Monarchy founded by *Nimrod*	2537	1831	2176
4. The Birth of *Abraham*	2714	2008	1999
5. The Destruction of *Sodom* and *Gomorrah* .	2816	2110	1897
6. The Beginning of the Kingdom of *Athens* by *Cecrops*	3157	2451	1556
7. *Moses* receives the Ten Commandments .	3222	2516	1491
8. The Entrance of the *Israelites* into *Canaan*	3262	2556	1451
9. The *Argonautic* Expedition	3420	2714	1293
10. The Destruction of *Troy*	3504	2798	1209
11. The Beginning of King *David*'s Reign .	3650	2944	1063
12. The Foundation of *Solomon*'s Temple .	3701	2995	1012
13. *Lycurgus* forms his excellent Laws . .	3829	3103	884
14. *Arbaces*, the first King of the *Medes* .	3838	3132	875
15. *Mandaucus*, the second	3865	3159	848
16. *Sosarmus*, the third	3915	3209	798
17. The Beginning of the *Olympiads* . . .	3938	3232	775
18. *Attica*, the fourth King of the *Medes* . .	3945	3239	768
19. The *Catonian Epocha* of the Building of *Rome*	3961	3255	752
20. The Æra of *Nabonassar*	3967	3261	746
21. The Destruction of *Samaria* by *Salmaneser*	3992	3286	721
22. The first Eclipse of the Moon on Record .	3993	3287	720
23. *Cardiceu*, the fifth King of the *Medes* .	3996	3290	717
24. *Phraortes*, the sixth	4058	3352	655
25. *Cyaxares*, the seventh	4080	3374	633
26. The first *Babylonish* Captivity by *Nebuchadnezzar*	4107	3401	606
27. The long War ended between the *Medes* and *Lydians*	4111	3405	602
28. The second *Babylonish* Captivity and Birth of *Cyrus*	4114	3408	599
29. The Destruction of *Solomon*'s Temple .	4125	3419	588
30. *Nebuchadnezzar* struck with Madness .	4144	3438	569
31. *Daniel*'s Vision of the four Monarchies	4158	3452	555
32. *Cyrus* begins to reign in the *Persian* Empire	4177	3471	536
33. The Battle of *Marathon*	4223	3517	490
34. *Artaxerxes Longimanus* begins to reign .	4249	3543	464
35. The Beginning of *Daniel*'s seventy Weeks of Years	4256	3550	457
36. The Beginning of the *Peloponnesian* War .	4282	3576	431
37. *Alexander*'s Victory at *Arbela* . . .	4383	3677	330
38. His Death	4390	3684	323
39. The Captivity of 100,000 *Jews* by King *Ptolemy*	4393	3687	320
40. The Colossus of *Rhodes* thrown down by an Earthquake	4491	3875	222
41. *Antiochus* defeated by *Ptolemy Philopater* .	4496	3790	217
42. The famous ARCHIMEDES murdered at *Syracuse*	4506	3800	207
43. *Jason* butchers the Inhabitants of *Jerusalem*	4543	3837	170
44. *Corinth* plundered and burnt by Consul *Mummius*	4567	3851	146
45. *Julius Cæsar* invades *Britain* . . .	4659	3953	54
45. He corrects the Calendar .	4677	3961	46
47. Is killed in the Senate-House . . .	4671	3965	42

	Julian Period.	Y. of the World.	Before Christ.
48. *Herod* made King of *Judea* - - - - - - -	4673	3967	40
49. *Anthony* defeated at the Battle of *Actium* - -	4683	3977	30
50. *Agrippa* builds the *Pantheon* at *Rome* - -	4688	3982	25
51. The true ÆRA of CHRIST's Birth - - -	4709	4003	4
52. The Death of *Herod* - - - - - - - - -	4710	4004	3
			After Christ.
53. The *Dyonisian* or vulgar ÆRA of CHRIST's Birth	4713	4007	0
54. The true year of his Crucifixion - - - -	4746	4040	33
55. The Destruction of *Jerusalem* - - - - - -	4783	4077	70
56. *Adrian* builds the Long Wall in *Britain* - -	4833	4127	120
57. *Constantius* defeats the *Picts* in *Britain* - -	5019	4313	306
58. The Council of *Nice* - - - - - - - - -	5038	4332	325
59. The Death of *Constantine the Great* - - -	5050	4344	337
60. The *Saxons* invited into *Britain* - - - -	5158	4452	445
61. The *Arabian Hegira* - - - - - - - - -	5335	4629	622
62. The Death of *Mohammed* the pretended Prophet	5343	4637	630
63. The *Persian Yesdegird* - - - - - - - -	5344	4638	631
64. The Sun, Moon, and all the Planets in *Libra*, *Sept.* 14, as seen from the Earth	5899	5193	1186
65. The Art of Printing discovered - - - -	6153	5447	1440
66. The Reformation begun by *Martin Luther* -	6230	5524	1517

Age of the world uncertain.

In fixing the year of the creation to the 706th year of the *Julian* Period, which was the 4007th year before the year of CHRIST's birth, I have followed Mr. *Bedford* in his Scripture-Chronology, printed A. D. 1730, and Mr. *Kennedy*, in a work of the same kind, printed A. D. 1762.—Mr. *Bedford* takes it only for granted that the world was created at the time of the autumnal equinox; but Mr. *Kennedy* affirms that the said equinox was at the noon of the fourth day of the creation-week, and that the moon was then 24 hours past her opposition to the Sun.—If *Moses* had told us the same things, we should have had sufficient *data* for fixing the *æra* of the creation; but as he has been silent on these points, we must consider the best accounts of chronologers as entirely hypothetical and uncertain.

TABLE I. *Shewing the Golden Number (which is the same both in the Old and New Styles) from the Christian Æra to A. D.* 380.

Hundreds of Years.		0 19 38 57 76 95	1 20 39 58 77 96	2 21 40 59 78 97	3 22 41 60 79 98	4 23 42 61 80 99	5 24 43 62 81	6 25 44 63 82	7 26 4 64 83	8 27 46 65 84	9 28 47 66 85	10 29 48 67 86	11 30 49 68 87	12 31 50 69 88	13 32 51 70 89	14 33 52 71 90	15 34 53 72 91	16 35 54 73 92	17 36 55 74 93	18 37 56 75 94
0	1900	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
100	2000	6	7	8	9	10	11	12	13	14	15	16	17	18	19	1	2	3	4	5
200	2100	11	12	13	14	15	16	17	18	19	1	2	3	4	5	6	7	8	9	10
300	2200	16	17	18	19	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
400	2300	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	1
500	2400	7	8	9	10	11	12	13	14	15	16	17	18	19	1	2	3	4	5	6
600	2500	12	13	14	15	16	17	18	19	1	2	3	4	5	6	7	8	9	10	11
700	2600	17	18	19	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
800	2700	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	1	2
900	2800	8	9	10	11	12	13	14	15	16	17	18	19	1	2	3	4	5	6	7
1000	2900	13	14	15	16	17	18	19	1	2	3	4	5	6	7	8	9	10	11	12
1100	3000	18	19	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1200	3100	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	1	2	3
1300	3200	9	10	11	12	13	14	15	16	17	18	19	1	2	3	4	5	6	7	8
1400	3300	14	15	16	17	18	19	1	2	3	4	5	6	7	8	9	10	11	12	13
1500	3400	19	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1600	3500	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	1	2	3	4
1700	3600	10	11	12	13	14	15	16	17	18	19	1	2	3	4	5	6	7	8	9
1800	3700	15	16	17	18	19	1	2	3	4	5	6	7	8	9	10	11	12	13	14

TABLE II. *Shewing the Number of Direction, for finding Easter Sunday by the Golden Number and Dominical Letter.*

G. N.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
A	26	19	5	26	2	33	19	12	26	19	5	26	12	5	26	2	33	19	12
B	27	13	6	27	13	34	20	13	27	20	6	27	13	6	20	13	34	20	6
C	28	14	7	21	14	35	21	7	28	21	7	28	14	7	21	14	26	21	7
D	29	15	8	22	15	29	22	8	29	15	8	29	15	1	22	15	29	22	8
E	30	16	2	23	16	30	23	9	30	16	9	23	16	2	23	9	30	23	9
F	24	17	3	24	10	31	24	10	31	17	10	24	17	3	24	10	31	17	10
G	25	18	4	25	11	32	18	11	32	18	4	25	18	4	25	11	32	18	11

This Table is adapted to the New Style.

TABLE III. *Shewing the Dominical Letters, Old Style, for 4200 Years before the Christian Æra.*

Bet. Christ				Hundreds of Years						
Years less than an Hundred				0	100	200	300	400	500	600
				700	800	900	1000	1100	[illegible]	1300
				1400	1500	1600	1700	1800	1900	2000
				2100	2200	2300	2400	2500	2600	2700
				2800	2900	[illegible]	3100	3200	3300	3400
				3500	3600	3700	3800	3900	4000	4100
0	28	56	84	D C	C B	B A	A G	G F	F E	E D
1	29	57	85	[illegible]	[illegible]	C	[illegible]	A	[illegible]	F
2	30	58	86	F	E	D	C	B	A	G
3	31	59	87	[illegible]	F	E	D	C	B	A
4	32	60	88	B A	A G	G F	F E	E D	D C	C B
5	33	61	89	C	B	A	G	F	E	D
6	34	62	90	D	C	B	A	[illegible]	F	E
7	35	63	91	E	D	C	B	A	G	F
8	36	64	92	G F	F E	E D	D C	C B	B A	A G
9	37	65	93	A	G	[illegible]	E	D	[illegible]	B
10	38	66	94	[illegible]	A	G	F	E	[illegible]	C
11	39	67	95	C	B	A	G	F	E	D
12	40	68	96	E D	D C	C B	B A	A G	G F	F E
13	41	69	97	F	E	D	C	[illegible]	A	G
14	42	70	98	G	F	E	[illegible]	C	B	A
15	43	71	99	A	G	F	E	D	C	B
16	44	72		C B	B A	A G	G F	F E	E D	D C
17	45	73		[illegible]	C	B	A	G	F	E
18	46	74		E	D	C	B	A	G	F
19	47	75		F	E	D	C	B	A	G
20	48	76		A G	G F	F E	E D	D C	C B	B A
21	49	77		B	A	G	F	E	D	C
[illegible]	50	78		C	B	A	G	F	E	D
23	51	79		D	C	B	A	G	F	E
24	52	80		F E	E D	D C	C B	B A	A G	G F
25	53	81		G	F	E	D	C	B	A
26	54	82		A	G	F	E	D	C	B
27	55	83		B	A	[illegible]	F	E	D	C

TABLE IV. *Shewing the Dominical Letters, Old Style, for 4200 Years after the Christian Æra.*

Aft. Christ.				Hundreds of Years.						
Years less than an Hundred.				0 700 1400 2100 [illegible] 3500	100 800 1500 2200 2900 3600	200 [illegible] 1600 2300 3000 3700	300 1000 1700 2400 3100 3800	400 1100 1800 2500 3200 3900	500 1200 1900 2600 3300 4000	600 1300 2000 2700 3400 4100
0	28	56	84	D C	E D	F E	G F	A G	B A	C B
1	29	57	85	B	C	D	E	F	G	A
2	30	58	86	A	B	C	D	E	F	G
3	[illegible]	59	87	G	A	B	C	[illegible]	E	F
4	32	60	88	F E	G F	A G	B A	C B	D C	E D
5	33	61	89	D	E	F	G	A	[illegible]	C
6	34	62	90	C	D	E	F	G	A	[illegible]
7	35	63	91	B	C	D	E	F	G	A
8	36	[illegible]	92	A G	B A	C B	D C	E D	F E	G F
9	37	65	93	F	G	A	B	C	D	E
10	38	66	94	E	F	G	A	[illegible]	[illegible]	D
11	39	67	95	D	E	F	G	A	B	[illegible]
12	40	68	[illegible]	C B	D C	E D	F E	G F	A G	B A
13	41	69	[illegible]	A	B	C	D	[illegible]	F	G
14	[illegible]	70	98	[illegible]	A	B	C	D	E	F
15	43	71	99	F	G	A	[illegible]	C	D	E
16	44	72		E D	F E	G F	A G	B A	C B	D C
17	45	73		C	D	E	F	G	A	B
18	46	74		B	C	D	E	F	G	A
19	47	75		A	B	C	D	[illegible]	F	G
20	48	76		G F	A G	B A	C B	D C	E D	F E
21	49	77		E	F	G	A	[illegible]	C	D
22	50	78		D	E	F	G	A	B	C
23	51	79		C	D	E	F	G	A	B
24	52	80		B A	C B	D C	E D	F E	G F	A G
25	53	[illegible]		G	A	B	[illegible]	D	[illegible]	F
26	54	[illegible]		F	G	A	B	C	D	E
27	55	83		E	F	G	[illegible]	B	C	D

Table V. *The Dominical Letter, New Style, for 4000 Years after the Christian Æra.*

After Chr.				Hundreds of Years.			
Years less than an Hundred.				100	200	300	400
				500	600	700	800
				900	1000	1100	1200
				1300	1400	1500	1600
				1700	1800	1900	2000
				2100	2200	2300	2400
				2500	2600	2700	2800
				[illegible]	3000	3100	3200
				3300	3400	3500	[illegible]
				3700	3800	3900	4000
				C	[illegible]	G	B A
1	29	57	85	B	D	F	G
2	30	58	86	[illegible]	C	E	F
3	31	59	87	G	B	D	E
4	32	60	88	F E	A G	C B	D C
5	33	61	89	D	F	A	B
6	34	62	90	C	E	G	[illegible]
7	35	63	91	B	D	F	[illegible]
8	36	64	92	A G	C B	E D	F E
9	37	65	93	[illegible]	A	C	[illegible]
10	38	66	[illegible]	E	[illegible]	B	C
11	39	[illegible]	95	D	F	A	B
12	40	68	[illegible]	C B	E D	G [illegible]	A G
13	41	69	97	A	[illegible]	[illegible]	F
14	42	70	98	G	B	[illegible]	[illegible]
15	43	71	99	[illegible]	A	C	B
16	44	72		E D	G F	B A	C B
17	45	73		C	E	G	A
18	46	74		B	D	F	G
19	47	75		A	C	E	F
20	48	76		G F	B A	D C	E D
21	49	77		E	G	B	[illegible]
22	50	78		D	F	A	[illegible]
23	51	79		C	E	G	A
44	52	80		B A	D C	F E	G F
25	53	81		G	B	D	[illegible]
26	54	82		F	A	C	D
27	55	83		E	G	B	C
28	56	84		D C	F E	A G	B A

TABLE VI. *Shewing the days of the Months, for both Styles, by the Dominical Letters.*

Week Days.	A	B	C	D	E	F	G
	1	2	3	4	5	6	7
	8	9	10	11	12	13	14
January 31	15	16	17	18	19	20	21
October 31	22	23	24	25	26	27	28
	29	30	31	—	—	—	—
				1	2	3	4
	5	6	7	8	9	10	11
Feb. 28-29	12	13	14	15	16	17	18
March 31	19	20	21	22	23	24	25
November 30	26	27	28	29	30	31	—
							1
	2	3	4	5	6	7	8
	9	10	11	12	13	14	15
April 30	16	17	18	19	20	21	22
July 31	23	24	25	26	27	28	29
	30	31					
			1	2	3	4	5
	6	7	8	9	10	11	12
	13	14	15	16	17	18	19
August 31	20	21	22	23	24	25	26
	27	28	29	30	31	—	—
						1	2
	3	4	5	6	7	8	9
	10	11	12	13	14	15	16
September 30	17	18	19	20	21	22	23
December 31	24	25	26	27	28	29	30
	31						
		1	2	3	4	5	6
	7	8	9	10	11	12	13
	14	15	16	17	18	19	20
May 31	21	22	23	24	25	26	27
	28	29	30	31			
					1	2	3
	4	5	6	7	8	9	10
	11	12	13	14	15	16	17
June 30	18	19	20	21	22	23	24
	25	26	27	28	29	30	

CHAP. XXII.

A Description of the Astronomical Machinery serving to explain and illustrate the foregoing Part of this Treatise.

Fronting the Title-page. The ORRERY. 397. THE ORRERY. This machine shews the motions of the Sun, Mercury, Venus, Earth, and Moon; and occasionally, the superior planets, Mars, Jupiter, and Saturn, may be put on; Jupiter's four satellites are moved round him in their proper times by a small winch, and Saturn has his five satellites, and his ring, which keeps its parallelism round the Sun; and by a lamp put in the Sun's place, the ring shews all the phases described in the 204th article.

The Sun. In the centre, No. 1. represents the SUN, supported by its axis inclining almost 8 degrees from the axis of the ecliptic; and turning round in $25\frac{1}{4}$ days on its axis, of which the north pole inclines toward the 8th degree of Pisces in the great ecliptic (No. II.), whereon the months and days are engraven over the signs and degrees in which the Sun appears, as seen from the Earth, on the different days of the year.

The ecliptic.

Mercury. The nearest planet (No. 2.) to the Sun is *Mercury*, which goes round him in 87 days 23 hours, or $87\frac{23}{24}$ diurnal rotations of the Earth; but has no motion round its axis in the machine, because the time of its diurnal motion in the heavens is not known to us.

Venus. The next planet in order is *Venus* (No. 3.) which performs her annual course in 224 days 17 hours; and turns round her axis in 24 days 8 hours, or in $24\frac{1}{3}$ diurnal rotations of the Earth. Her axis inclines 75 degrees from the axis of the ecliptic, and her north pole inclines toward the 20th degree of Aquarius, according to the observations of

Bianchini. She shews all the phenomena described from the 30th to the 44th article in chap. 1.

Next without the orbit of Venus is the *Earth,* (No. 4.) which turns round its axis, to any fixed point at a great distance, in 23 hours 56 minutes 4 seconds, of mean solar time (§ 221, *& seq.*), but from the sun to the Sun again in 24 hours of the same time. No. 6. is a sidereal dial plate under the Earth; and No. 7. a solar dial-plate on the cover of the machine. The index of the former shews sidereal, and of the latter, solar time; and hence, the former index gains one entire revolution on the latter every year, as 365 solar or natural days contain 366 sidereal days, or apparent revolutions of the stars. In the time that the Earth makes 365¼ diurnal rotations on its axis, it goes once round the Sun in the plane of the ecliptic; and always keeps opposite to a moving index (No. 10.), which shews the Sun's apparent daily change of place, and also the days of the months. The Earth.

The Earth is half covered with a black cap, to divide the apparently-enlightened half next the Sun from the other half, which when turned away from him is in the dark. The edge of the cap represents *the circle bounding light and darkness*, and shews at what time the Sun rises and sets to all places throughout the year. The Earth's axis inclines 23½ degrees from the axis of the ecliptic, the north pole inclines toward the beginning of Cancer, and keeps its parallelism throughout its annual course, § 48, 202; so that in summer the northern parts of the Earth inclines toward the Sun, and in winter declines from him: by which means the different lengths of days and nights, and the cause of the various seasons, are demonstrated to sight.

There is a broad horizon, to the upper side of which is fixed a meridian-semicircle in the north and south points, graduated on both sides from the horizon to 90° in the zenith, or vertical point. The edge

of the horizon is graduated from the east and west to the south and north points, and within these divisions are the points of the compass. From the lower side of this thin horizon-plate, stand out four small wires, to which is fixed a twilight-circle 18 degrees from the graduated side of the horizon all round. This horizon may be put upon the Earth (when the cap is taken away), and rectified to the latitude of any place: and then, by a small wire called *the solar ray*, which may be put on so as to proceed directly from the Sun's centre toward the Earth's, but to come no farther than almost to touch the horizon. The beginning of twilight, time of sun-rising, with his amplitude, meridian-altitude, time of setting, amplitude then, and end of twilight, are shewn for every day of the year, at *that* place to which the horizon is rectified.

The Moon. The Moon (No. 5.) goes round the Earth, from between it and any fixed point at a great distance, in 27 days 7 hours 43 minutes, or through all the signs and degrees of her orbit; which is called *her periodical revolution*: but she goes round from the Sun to the Sun again, or from change to change, in 29 days 12 hours 45 minutes, which is *her synodical revolution;* and in that time she exhibits all the phases already described, § 255.

When the above-mentioned horizon is rectified to the latitude of any given place, the times of the Moon's rising and setting, together with her amplitude, are shewn to that place as well as the Sun's, and all the various phenomena of the harvest-moon, § 273, &c *seq.* are made obvious to sight.

The nodes. The Moon's orbit (No. 9.) is inclined to the ecliptic (No. 11.), one half being above, and the other below it. The nodes, or points at 0 and 0, lie in the plane of the ecliptic, as described § 317, 318, and shift backward through all its signs and degrees in 18⅔ years. The degrees of the Moon's latitude, to

the highest at *N L* (north latitude), and lowest at *S L* (south latitude), are engraven both ways from her nodes at 0 and 0; and as the Moon rises and falls in her orbit according to its inclination, her latitude and distance from her nodes are shewn for every day; having first rectified her orbit so as to set the nodes to their proper places in the ecliptic: and then, as they come about at different, and almost opposite, times of the year, § 319, and point twice toward the Sun; all the eclipses may be shewn for hundreds of years (without any new rectification) by turning the machinery backward for time past, or forward for time to come. At 17 degrees distance from each node, on both sides, is engraven a small sun; and at 12 degrees distance, a small moon; which shew the limits of solar and lunar eclipses, § 317: and when, at any change, the moon falls between either of these suns and the node, the Sun will be eclipsed on the day pointed to by the annual index (No. 10.), and as the Moon has then north or south latitude, one may easily judge whether that eclipse will be visible in the northern or southern hemisphere; especially as the Earth's axis inclines toward the Sun or declines from him at that time. And when at any full, the Moon falls between either of the little moons and node, she will be eclipsed, and the annual index shews the day of that eclipse. There is a circle of 29½ equal parts (No. 8.) on the cover of the machine, on which an index shews the days of the Moon's age.

A semi-ellipsis and semicircle are fixed to an elliptical ring, which being put like a cap upon the Earth, and the forked part *F* upon the Moon, shews the tides as the Earth turns round within them, and they are led round it by the Moon. When the different places come to the semi-ellipsis *AaEbB*, they have tides of flood: and when they come to the semicircle *CED*, they have tides of ebb, § 304, 305; *Plate IX. Fig. X.*

the index on the hour-circle (No. 7.) shewing the times of these phenomena.

There is a jointed wire, of which one end being put into a hole in the upright stem that holds the Earth's cap, and the wire laid into a small forked piece which may be occasionally put upon Venus or Mercury, shews the direct and retrograde motions of these two planets, with their stationary times and places as seen from the Earth.

The whole machinery is turned by a winch or handle (No. 12.), and is so easily moved, that a clock might turn it without any danger of stopping.

To give a plate of the wheel work of this machine would answer no purpose, because many of the wheels lie so behind others, as to hide them from sight in any view whatsoever.

Another Orrery. *Plate VI.* Fig. I.

398. *Another* Orrery. In this machine, which is the simplest I ever saw, for shewing the diurnal and annual motions of the Earth, together with the motion of the Moon and her nodes, *A* and *B* are two oblong square plates held together by four upright pillars; of which three appear at *f*, *g*, and *g* 2. Under the plate *A* is an endless screw on the axis of the handle *b*, which works in a wheel fixed on the same axis with the double-grooved wheel *E*; and on the top of this axis is fixed the toothed wheel *i*, which turns the pinion *k*, on the top of whose axis is the pinion *k* 2, which turns another pinion *b* 2, and that turns a third, which being fixed on *a* 2, the axis of the Earth *U*, turns it round, and the earth with it: this last axis inclines in an angle of 23½ degrees. The supporter *X* 2, in which the axis of the earth turns, is fixed to the moveable plate *C*.

In the fixed plate *B*, beyond *H*, is fixed the strong wire *d*, on which hangs the sun *T*, so as it may turn round the wire. To this sun is fixed the wire or solar ray *Z*, which (as the earth *U* turns round its axis) points to all the places that the Sun passes vertically over, every day of the year. The earth is half co-

vered with a black cap *a*, as in the former Orrery, for dividing the day from the night; and as the different places come out from below the edge of the cap, or go in below it, they shew the times of sun-rising and setting every day of the year. This cap is fixed on the wire *b*, which has a forked piece *C* turning round the wire *d*: and, as the earth goes round the sun, it carries the cap, wire, and solar ray round him; so that the solar ray constantly points toward the earth's centre.

On the axis of the pinion *k* is the pinion *m*, which turns a wheel on the cock or supporter *n*, and on the axis of this wheel nearest *n* is a pinion (hid from view) under the plate *C*, which pinion turns a wheel that carries the moon *V* round the earth *U*; the moon's axis rising and falling in the socket *W*, which is fixed to the triangular piece above *Z*; and this piece is fixed to the top of the axis of the last-mentioned wheel. The socket *W* is slit on the outermost side: and in this slit the two pins near *Y*, fixed in the moon's axis, move up and down; one of them being above the inclined plane *YX*, and the other below it. By this mechanism, the moon *V* moves round the earth *T* in the inclined orbit *q*, parallel to the plane of the ring *YX*; of which the descending node is at *X*, and the ascending node opposite to it, but hid by the supporter *X* 2.

The small wheel *E* turns the large wheels *D* and *F*, of equal diameters, by cat-gut strings crossing between them: and the axes of these two wheels are cranked at *G* and *H*, above the plate *B*. The upright stems of these cranks going through the plate *C*, carry it over and over the fixed plate *B*, with a motion which carries the earth *U* round the sun *T*, keeping the earth's axis always parallel to itself, or still inclining toward the left hand of the plate; and shewing the vicissitudes of seasons, as described in the tenth chapter. As the earth goes round the sun

the pinion *k* goes round the wheel *i*, for the axis of *k* never touches the fixed plate *B*, but turns on a wire fixed into the plate *C*.

On the top of the crank *G* is an index *L*, which goes round the circle *m* 2 in the time that the earth goes round the sun, and points to the days of the months; which, together with the names of the seasons, are marked in this circle.

This index has a small grooved wheel *L* fixed upon it, round which, and the plate *Z*, goes a catgut string crossing between them; and by this means the moon's inclined plane *YX*, with its nodes, is turned backward, for shewing the times and returns of eclipses, § 310, 320.

The following parts of this machine must be considered as distinct from those already described.

Toward the right hand, let *S* be the earth hung on the wire *e*, which is fixed into the plate *B*; and let *O* be the moon fixed on the axis *M*, and turning round within the cap *P*, in which, and in the plate *C*, the crooked wire *Q* is fixed. On the axis *M* is also fixed the index *K*, which goes round a circle *h* 2, divided into $29\frac{1}{2}$ equal parts, which are the days of the Moon's age: but to avoid confusion in the scheme, it is only marked with the numeral figures 1 2 3 4, for the quarters. As the crank *H* carries this moon round the earth *S* in the orbit *t*, she shews all her phases by means of the cap *P* for the different days of her age, which are shewn by the index *K*; this index turning just as the moon *O* does, demonstrates her turning round her axis, as she still keeps the same side toward the earth *S*. § 262.

At the other end of the plate *C*, a moon *N* goes round an earth *R* in the orbit *p*. But this moon's axis is stuck fast into the plate *C* at *S* 2, so that neither moon nor axis can turn round; and as this moon goes round her earth, she shews herself all round to it; which proves, that if the Moon was seen all round

from the Earth in a lunation, she could not turn round her axis.

N. B. If there were only the two wheels *D* and *F*, with a cat-gut string over them, but not crossing between them, the axis of the earth *U* would keep its parallelism round the Sun *T*, and shew all the seasons; as I sometimes make these machines: and the moon *O* would go round the earth *S*, shewing her phases as above; as likewise would the moon *N* round the earth *R*; but then neither could the diurnal motion of the earth *U* on its axis be shewn, nor the motion of the moon *V* round the earth.

399. In the year 1746 I contrived a very simple machine, and described its performance in a small Treatise upon the Phenomena of the Harvest-Moon, published in the year 1747. I improved it soon after, by adding another wheel, and called it *The Calculator*. It may be easily made by any gentleman who has a mechanical genius. The Calculator.

The great flat ring supported by twelve pillars, and on which the twelve signs with their respective degrees are laid down, is the ecliptic; nearly in the centre of it is the sun *S*, supported by the strong crooked wire *I*; and from the sun proceeds a wire *W*, called the *solar ray*, pointing toward the centre of the earth *E*, which is furnished with a moveable horizon *H*, together with a brazen meridian, and quadrant of altitude. *R* is a small ecliptic, whose plane coincides with that of the great one, and has the like signs and degrees marked upon it; and is supported by two wires *D* and *D*, which are put into the plane *PP*, but may be taken off at pleasure. As the earth goes round the sun, the signs of this small circle keep parallel to themselves, and to those of the great ecliptic. When it is taken off, and the solar ray *W* drawn farther out, so as almost to touch the horizon *H*, or the quadrant of altitude, the horizon being rec- *Plate VIII. Fig. I.*

tified to any given latitude, and the earth turned round its axis by hand, the point of the wire *W* shews the sun's declination in passing over the graduated brass meridian, and his height at any given time upon the quadrant of altitude, together with his azimuth, or point of bearing upon the horizon at that time; and likewise his amplitude, and time of rising and setting by the hour-index, for any day of the year that the annual-index *U* points to in the circle of months below the sun. *M* is a solar-index or pointer supported by the wire *L*, which is fixed into the knob *K*: the use of this index is to shew the Sun's place in the ecliptic every day in the year; for it goes over the signs and degrees as the index *U* goes over the months and days; or rather, as they pass under the index *U*, in moving the cover-plate with the earth and its furniture round the sun; for the index *U* is fixed tight on the immoveable axis in the centre of the machine. *K* is a knob or handle for moving the earth round the sun, and the moon round the earth.

As the earth is carried round the sun, its axis constantly keeps the same oblique direction, or parallel to itself, § 48, 202, shewing thereby the different lengths of days and nights at different times of the year, with all the various seasons. And, in one annual revolution of the earth, the moon *M* goes 12⅓ times round it from change to change, having an occasional provision for shewing her different phases. The lower end of the moon's axis bears by a small friction-wheel upon the inclined plane *T*, which causes the moon to rise above and sink below the ecliptic *R* in every lunation; crossing it in her nodes, which shift backward through all the signs and degrees of the said ecliptic, by the retrograde motion of the inclined plane *T*, in 18 years and 225 days. On this plane the degrees and parts of the moon's north and south latitude are laid down from both

the nodes, one of which, viz. the descending node, appears at 0, by *DN* above *B*; the other node being hid from sight on this plane by the plate *PP*; and from both nodes, at proper distances, as in the other Orrery, the limits of eclipses are marked, and all the solar and lunar eclipses are shewn in the same manner, for any given year within the limits of 6000, either before or after the Christian æra. On the plate that covers the wheel-work, under the Sun *S*, and round the knob *K*, are astronomical tables, by which the machine may be rectified to the beginning of any given year within these limits, in three or four minutes of time; and when once set right, may be turned backward for 300 years past, or forward for as many to come, without requiring any new rectification. There is a method for its adding up the 29th of *February* every fourth year, and allowing only 28 days to that month for every other three; but all this being performed by a particular manner of cutting the teeth of the wheels, and dividing the month-circle, too long and intricate to be described here, I shall only shew how these motions may be performed near enough for common use, by wheels with grooves and cat-gut strings round them; only here I must put the operator in mind, that the groove are to be made sharp-bottomed, (not round) to keep the strings from slipping.

The moon's axis moves up and down in the socket *N*, fixed into the bar *O*, (which carries her round the earth) as she rises above or sinks below the ecliptic; and immediately below the inclined plane *T* is a flat circular plate (between *Y* and *T*) on which the different eccentricities of the Moon's orbit are laid down; and likewise her mean anomaly and elliptic equation, by which her true place may be very nearly found at any time. Below this apogee plate, which shews the anomaly, &c. is a circle *Y* divided into 29½ equal parts, which are the

days of the Moon's age: and the forked end *A* of the index *AB* (Fig. II.) may be put into the apogee-part of this plate; there being just such another index to put into the inclined plane *T* at the ascending node: and then the curved points *B* of these indexes shew the direct motion of the apogee, and retrograde motion of the nodes through the ecliptic *R*, with their places in it at any given time. As the moon *M* goes round the earth *E*, she shews her place every day in the ecliptic *R*, and the lower end of her axis shews her latitude and distance from her node on the inclined plane *T*, also her distance from her apogee and perigee, together with her mean anomaly, the then eccentricity of her orbit, and her elliptic equation, all on the apogee-plate, and the day of her age in the circle *Y* of 29½ equal parts, for every day of the year, pointed out by the annual index *U* in the circle of months.

Having rectified the machine by the tables for the beginning of any year, move the earth and moon forward by the knob *K*, until the annual index comes to any given day of the month, then stop, and not only all the above phenomena may be shewn for that day, but also, by turning the earth round its axis, the declination, azimuth, amplitude, altitude of the Moon at any hour, and the times of her rising and setting, are shewn by the horizon, quadrant of altitude, and hour-index. And in moving the earth round the sun, the days of all the new and full moons and eclipses in any given year are shewn. The phenomena of the harvest-moon, and those of the tides, by such a cap as that in plate IX. Fig. 10. put upon the earth and moon, together with the solution of many problems not here related, are made conspicuous.

The easiest, though not the best, way, that I can instruct any mechanical person to make the wheel-

work of such a machine, is as follows: which is the way that I made it, before I thought of numbers exact enough to make it worth the trouble of cutting teeth in the wheels.

Fig. 3d of Plate VIII. is a section of this machine; in which *ABCD* is a frame of wood held together by four pillars at the corners; two of which appear at *AC* and *BD*. In the lower plate *CD* of this frame are three small friction-wheels, at equal distances from each other; two of them appearing at *e* and *e*. As the frame is moved round, these wheels run upon the fixed bottom-plate *EE*, which supports the whole work. PLATE VIII. Fig. III.

In the centre of this last-mentioned plate is fixed the upright axis *GFFf*, and on the same axis is fixed the wheel *HHH*, in which are four grooves, *I*, *X*, *k*, *L*, of different diameters. In these grooves are cat-gut strings going also round the separate wheels *M*, *N*, *O*, and *P*.

The wheel *M* is fixed on a solid spindle or axis, the lower pivot of which turns at *R* in the under plate of the moveable frame *ABCD;* and on the upper end of this axis is fixed the plate *oo* (which is *PP*, under the earth, in Fig. 1.), and to this plate is fixed at an angle of 23½ degrees inclination, the dial-plate below the earth *T;* on the axis of which, the index *q* is turned round by the earth. This axis, together with the wheel *M*, and plate *oo*, keep their parallelism in going round the sun *S*.

On the axis of the wheel *M* is a moveable socket, on which the small wheel *N* is fixed, and on the upper end of this socket is put on tight (but so as it may be occasionally turned by hand) the bar *ZZ* (viz. the bar *O* in Fig. 1.) which carries the moon *m* round the earth *T*, by the socket *n*, fixed into the bar. As the moon goes round the earth, her axis rises and falls in the socket *n;* because, on the lower end of her axis, which is turned inward, there is a small friction-wheel *s* running

on the inclined plane *X* (which is *T* in Fig. 1.), and so causes the moon alternately to rise above and sink below the little ecliptic *VV* (*R* in Fig. 1.) in every lunation.

On the socket or hollow axis of the wheel *N*, there is another socket, on which the wheel *O* is fixed; and the moon's inclined plane *X* is put tightly on the upper end of this socket, not on a square, but on a round, that it may be occasionally set by hand without wrenching the wheel or axle.

Lastly, on the hollow axis of the wheel *O* is another socket, on which is fixed the wheel *P*, and on the upper end of this socket is put on tightly the apogee-plate *Y* (*that* immediately below *T* in Fig. 1.) All these axles turn in the upper plate of the moveable frame at *Q*; which plate is covered with the thin plate *cc* (screwed to it), whereon are the forementioned tables and month-circle in Fig. 1.

The middle part of the thick fixed wheel *HHH* is much broader than the rest of it, and comes out between the wheels *M* and *O* almost to the wheel *N*. To adjust the diameters of the grooves of this fixed wheel to the grooves of the separate wheels *M*, *N*, *O*, and *P*, so as they may perform their motion in their proper times, the following method must be observed.

The groove of the wheel *M*, which keeps the parallelism of the earth's axis, must be precisely of the same diameter as the lower groove *I* of the fixed wheel *HHH*; but, when this groove is so well adjusted as to shew, that in ever so many annual revolutions of the Earth, its axis keeps its parallelism, as may be observed by the solar ray *W* (Fig. 1.) always coming precisely to the same degree of the small ecliptic *R* at the end of every annual revolution, when the index *M* points to the like degree in the great ecliptic; then, with the edge of a thin file, give the groove of the wheel *M* a small rub all round, and, by that means lessening

the diameter of the groove perhaps about the 20th part of a hair's breadth, it will cause the earth to shew the precession of the equinoxes; which, in many annual revolutions, will begin to be sensible, as the earth's axis deviates slowly from its parallelism, § 246, toward the antecedent signs of the ecliptic.

The diameter of the groove of the wheel *N*, which carries the moon round the earth, must be to the diameter of the groove *X*, as a lunation is to a year, that is, as $29\frac{1}{2}$ to $365\frac{1}{4}$.

The diameter of the groove of the wheel *O*, which turns the inclined plane *X* with the moon's nodes backward, must be to the diameter of the groove *k*, as 20 to $18\frac{45}{73}$. And,

Lastly, the diameter of the groove of the wheel *P*, which carries the moon's apogee forward, must be to the diameter of the groove *L*, as 70 to 62.

But after all this nice adjustment of the grooves to the proportional times of their respective wheels turning round, and which seems to promise very well in theory, there will still be found a necessity of a farther adjustment by hand; because proper allowance must be made for the diameters of the cat-gut strings: and the grooves must be so adjusted by hand, as, that in the time the earth is moved once round the sun, the moon must perform 12 synodical revolutions round the earth, and be almost 11 days old in her 13th revolution. The inclined plane with its nodes must go once round backward through all the signs and degrees of the small ecliptic in 18 annual revolutions of the earth, and 225 days over. And the apogee-plate must go once round forward, so as its index may go over all the signs and degrees of the small ecliptic in eight years (or so many annual revolutions of the earth) and 312 days over.

N. B. The string which goes round the grooves *X* and *N*, for the moon's motion, must cross between these wheels; but all the rest of the strings

go in their respective grooves, *IMk*, *O*, and *LP*, without crossing.

The COMETARIUM.

400. The COMETARIUM. This curious machine shews the motion of a comet, or eccentric body moving round the Sun, describing equal areas in equal times, § 152, and may be so contrived as to shew such a motion for any degree of eccentricity. It was invented by the late Dr. DESAGULIERS.

Plate IV. Fig. IV.

The dark elliptical groove round the letters *abcdefghiklm* is the orbit of the comet *Y*: this comet is carried round in the groove, according to the order of letters, by the wire *W* fixed in the sun *S*, and slides on the wire as it approaches nearer to, or recedes farther from, the sun; being nearest of all in the perihelion *a*, and farthest in the aphelion *g*. The areas *aSb*, *bSc*, *cSd*, &c. or contents of these several triangles, are all equal: and in every turn of the winch *N*, the comet *Y* is carried over one of these areas: consequently, in as much time as it moves from *f* to *g*, or from *g* to *h*, it moves from *m* to *a*, or from *a* to *b*; and so of the rest, being quickest of all at *a*, and slowest at *g*. Thus the comet's velocity in its orbit continually decreases from the perihelion *a* to the aphelion *g*; and increases in the same proportion from *g* to *a*.

The elliptical orbit is divided into 12 equal parts or signs, with their respective degrees, and so is the circle *nopqrstu*, which represents a great circle in the heavens, and to which the comet's motion is referred by a small knob on the point of the wire *W*. While the comet moves from *f* to *g* in its orbit, it appears to move only about 5 degrees in this circle, as is shewn by the small knob on the end of the wire *W*; but in the like time, as the comet moves from *m* to *a*, or from *a* to *b*, it appears to describe the large space *tn* or *no* in the heavens, either of which spaces contains 120 degrees, or four signs. Were the eccentricity of its orbit greater,

the greater still would be the difference of its motion, and *vice versa.*

ABCDEFGHIKLMA is a circular orbit for shewing the equal motion of a body round the sun *S*, describing equal areas *ASB*, *BSC*, &c. in equal times with those of the body *Y* in its elliptical orbit, above mentioned; but with this difference, that the circular motion describes the equal arcs *AB*, *BC*, &c. in the same equal times that the elliptical motion describes the unequal arcs *ab*, *bc*, &c.

Now, suppose the two bodies *Y* and 1 to start from the points *a* and *A* at the same moment of time, and each having gone round its respective orbit, to arrive at these points again at the same instant, the body *Y* will be forwarder in its orbit than the body 1 all the way from *a* to *g*, and from *A* to *G*; but 1 will be forwarder than *Y* through all the other half of the orbit; and the difference is equal to the equation of the body *Y* in its orbit. At the points *a*, *A*, and *g*, *G*, that is in the perihelion and aphelion, they will be equal; and then the equation vanishes. This shews why the equation of a body moving in an elliptic orbit, is added to the mean or supposed-circular motion, from the perihelion to the aphelion; and subtracted, from the aphelion to the perihelion, in bodies moving round the Sun, or from the perigee to the apogee, and from the apogee to the perigee, in the Moon's motion round the Earth, according to the precepts in the 353d article; only we are to consider, that when motion is turned into time, it reverses the titles in the table of *The Moon's elliptic Equation.*

This motion is performed in the following manner by the machine. *ABC* is a wooden bar (in the box containing the wheel-work), above which are the wheels *D* and *E*; and below it the elliptic plates *FF* and *GG*; each plate being fixed on an axis in one of its focuses, at *E* and *K*: and the wheel *E* is fixed on the same axis with the plate *FF*. These *Plate IV. Fig. V.*

plates have grooves round their edges precisely of equal diameters to one another, and in these grooves is the cat-gut strings *gg*, *gg*, crossing between the plates at *h*. On *H* (the axis of the handle or winch *N* in Fig. 4th) is an endless screw in Fig. 5, working in the wheels *D* and *E*, whose numbers of teeth being equal, and should be equal to the number of lines *aS*, *bS*, *cS*, &c. in Fig. 4, they turn round their axes in equal times to one another, and to the motion of the elliptic plates. For the wheels *D* and *E* having an equal number of teeth, the plate *FF* being fixed on the same axis with the wheel *E*, and the plate *FF* turning the equally large plate *GG*, by a cat-gut string round them both, they must all go round their axes in as many turns of the handle *N* as either of the wheels has teeth.

It is easy to see, that the end *h* of the elliptical plate *FF* being farther from its axis *E* than the opposite end *i* is, must describe a circle so much the larger in proportion; and must therefore move through so much more space in the same time; and for that reason the end *h* moves so much faster than the end *i*, although it goes no sooner round the centre *E*. But then, the quick-moving end *h* of the plate *FF* leads about the short end *h K* of the plate *GG* with the same velocity; and the slow-moving end *i* of the plate *FF* coming half round, as to *B*, must then lead the long end *k* of the plate *GG* as slowly about. So that the elliptical plate *FF* and it axis *E* move uniformly and equally quick in every part of its revolution; but the elliptical plate *GG*, together with its axis *K*, must move very unequally in different parts of its revolution; the difference being always inversely as the distance of any points of the circumference of *GG* from its axis at *K*: or in other words, to instance in two points; if the distance *Kk*, be four, five, or six times as great as the distance *Kh*, the point *h* will move in that position four, five, or six

times as fast as the point *k* does; when the plate *GG* has gone half round: and so on for any other eccentricity or difference of the distances *Kk* and *Kh*. The tooth *i* on the plate *FF* falls in between the two teeth at *k* on the plate *GG*, by which means the revolution of the latter is so adjusted to that of the former, that they can never vary from one another.

On the top of the axis of the equally-moving wheel *D*, in Fig. 5th, is the sun *S* in Fig. 4th; which sun, by the wire *Z* fixed to it, carries the ball 1 round the circle *ABCD*, &c. with an equable motion according to the order of the letters; and on the top of the axis *K* of the unequally-moving ellipsis *GG*, in Fig. 5th, is the sun *S* in Fig. 4th, carrying the ball *Y* unequally round in the elliptical groove *abcd*, &c. *N. B.* This elliptical groove must be precisely equal and similar to the verge of the plate *GG*, which is also equal to that of *FF*.

In this manner, machines may be made to shew the true motion of the Moon about the Earth, or of any planet about the Sun; by making the elliptical plates of the same eccentricities, in proportion to the radius, as the orbits of the planets are whose motions they represent; and so, their different equations, in different parts of their orbits, may be made plain to the sight: and clearer ideas of these motions and equations will be acquired in half an hour, than could be gained from reading half a day about them.

401. The IMPROVED CELESTIAL GLOBE. On the north pole of the axis, above the hour-circle, is fixed an arch *MKH* of $23\frac{1}{2}$ degrees; and at the end *H* is fixed an upright pin *HG*, which stands directly over the north pole of the ecliptic, and perpendicular to that part of the surface of the globe. On this pin are two moveable collets at *D* and *H*, to which are fixed the quadrantal wires *N* and *O*,

The improved CELESTIAL GLOBE.

Plate III. Fig. III.

having two little balls on their ends for the sun and moon, as in the figure. The collet *D* is fixed to the circular plate *F*, on which the 29½ days of the Moon's age are engraven, beginning just under the sun's wire *N*; and as this wire is moved round the globe, the plate *F* turns round with it. These wires are easily turned, if the screw *G* be slackened; and when they are set to their proper places, the screw serves to fix them there; so that when the globe is turned, the wires with the sun and moon may go round with it; and these two little balls rise and set at the same times, and on the same points of the horizon, for the day to which they are rectified, as the Sun and Moon do in the heavens.

Because the Moon keeps not her course in the ecliptic (as the Sun appears to do) but has a declination of 5⅓ degrees, on each side, from it in every lunation, § 317, her ball may be screwed as many degrees to either side of the ecliptic as her latitude, or declination from the ecliptic, amounts to, at any given time; and for this purpose *S* is a small piece of pasteboard, of which the curved edge at *S* is to be set upon the globe, at right angles to the ecliptic, and the dark line over *S* to stand upright upon it. From this line, on the convex edge, are drawn the 5⅓ degrees of the Moon's latitude on both sides of the ecliptic; and when this piece is set upright on the globe, its graduated edge reaches to the moon on the wire *O*, by which means she is easily adjusted to her latitude found by an ephemeris.

The horizon is supported by two semicircular arches, because pillars would stop the progress of the balls, when they go below the horizon in an oblique sphere.

To rectify it. *To rectify this globe.* Elevate the pole to the latitude of the place; then bring the Sun's place in the ecliptic for the given day to the brass meridian, and set the hour-index to XII at noon, that is,

to the upper XII on the hour-circle, keeping the globe in that situation; slacken the screw *G*, and set the sun directly over his place on the meridian; which being done, set the moon's wire under the number that expresses her age for that day on the plate *F*, and she will then stand over her place in the ecliptic, and shew what constellation she is in. Lastly, fasten the screw *G*, and laying the curved edge of the pasteboard *S* over the ecliptic, below the moon, adjust the moon to her latitude over the graduated edge of the pasteboard; and the globe will be rectified.

Having thus rectified the globe, turn it round, and observe on what points of the horizon the sun and moon balls rise and set, for these agree with the points of the compass on which the Sun and Moon rise and set in the heavens on the given day: and the hour-index shews the times of their rising and setting; and likewise the time of the Moon's passing over the meridian. Its use.

This simple apparatus shews all the varieties that can happen in the rising and setting of the Sun and Moon; and makes the forementioned phenomena of the harvest-moon (Chap. xvi.) plain to the eye. It is also very useful in reading lectures on the globes, because a large company can see this sun and moon go round, rising above and setting below the horizon at different times, according to the seasons of the year; and making their appulses to different fixed stars. But in the usual way, where there is only the places of the Sun and Moon in the ecliptic to keep the eye upon, they are easily lost sight of, unless they be covered with patches.

402. THE PLANETARY GLOBES. In this machine, *T* is a terrestrial globe fixed on its axis standing upright on the pedestal *CDE*, on which is an hour-circle, having its index fixed on the axis, which turns somewhat tightly in the pedestal, so The PLANETARY GLOBE. *Plate VIII.* Fig IV.

that the globe may not be liable to shake; to prevent which, the pedestal is about two inches thick, and the axis goes quite through it, bearing on a shoulder. The globe is hung in a graduated brazen meridian much in the usual way; and the thin plate *N*, *NE*, *E*, is a moveable horizon, graduated round the outer edge, for shewing the bearings and amplitudes of the Sun, Moon, and planets. The brazen meridian is grooved round the outer edge: and in this groove is a slender semicircle of brass, the ends of which are fixed to the horizon in its north and south points: this semicircle slides in the groove as the horizon is moved in rectifying it for different latitudes. To the middle of the semicircle is fixed a pin, which always keeps in the zenith of the horizon, and on this pin, the quadrant of altitude *q* turns; the lower end of which, in all positions, touches the horizon as it is moved round the same. This quadrant is divided into 90 degrees from the horizon to the zenith-pin on which it is turned, at 90. The great flat circle or plate *AB* is the ecliptic, on the outer edge of which the signs and degrees are laid down; and every fifth degree is drawn through the rest of the surface of this plate toward its centre. On this plate are seven grooves, to which seven little balls are adjusted by sliding wires, so that they are easily moved in the grooves without danger of starting out of them. The ball next the terrestrial globe is the moon, the next without it is Mercury, the next Venus, the next the sun, then Mars, then Jupiter, and lastly Saturn; and in order to know them, they are separately stampt with the following characters; ●, ☿, ♀, ☉, ♂, ♃, ♄. This plate or ecliptic is supported by four strong wires, having their lower ends fixed into the pedestal, at *C*, *D*, and *E*; the fourth being hid by the globe. The ecliptic is inclined 23½ degrees to the pedestal, and is there-

fore properly inclined to the axis of the globe which stands upright on the pedestal.

To rectify this machine. Set the sun and all the planetary balls to the geocentric places in the ecliptic for any given time, by an ephemeris; then set the north point of the horizon to the latitude of your place on the brazen meridian, and the quadrant of altitude to the south point of the horizon; which done, turn the globe with its furniture till the quadrant of altitude comes right against the Sun, viz. to his place in the ecliptic; and keeping it there, set the hour-index to the XII next the letter *C*; and the machine will be rectified, not only for the following problems, but for several others, which the artist may easily find out.

PROBLEM I.

To find the Amplitudes, Meridian-Altitudes, and Times of rising, culminating, and setting, of the Sun, Moon, and Planets.

Turn the globe round eastward, or according to the order of the signs; and when the eastern edge of the horizon comes right against the sun, moon, or any planet, the hour-index will shew the time of its rising; and the inner edge of the ecliptic will cut its rising-amplitude in the horizon. Turn on, and when the quadrant of altitude comes right against the sun, moon, or any planet, the ecliptic will cut their meridian-altitudes on the quadrant, and the hour-index will shew the times of their coming to the meridian. Continue turning, and when the western edge of the horizon comes right against the sun, moon, or any planet, their setting-amplitudes will be cut on the horizon by the ecliptic; and the times of their setting will be shewn by the index on the hour-circle. Its use.

PROBLEM II.

To find the Altitude and Azimuth of the Sun, Moon, and Planets, at any Time of their being above the Horizon.

Turn the globe till the index comes to the given time in the hour-circle; then keep the globe steady; and moving the quadrant of altitude to each planet respectively, the edge of the ecliptic will cut the planet's mean altitude on the quadrant, and the quadrant will cut the planet's azimuth, or point of bearing on the horizon.

PROBLEM III.

The Sun's Altitude being given at any Time either before or after Noon, to find the Hour of the Day, and the Variation of the Compass, in any known Latitude.

With one hand hold the edge of the quadrant right against the sun; and with the other hand, turn the globe westward, if it be in the forenoon, or eastward if it be in the afternoon, until the sun's place at the inner edge of the ecliptic cuts the quadrant in the sun's observed altitude, and then the hour-index will point out the time of the day, and the quadrant will cut the true azimuth or bearing of the sun for that time: the difference between which, and the bearing shewn by the azimuth-compass, is the variation of the compass in that place of the Earth.

The Trajectorium Lunare.

403. THE TRAJECTORIUM LUNARE. This machine is for delineating the paths of the Earth and Moon, shewing what sort of curves they make in the ethereal regions; and was just mentioned in

the 266th article. *S* is the sun, and *E* the earth, whose centres are 81 inches distant from each other; every inch answering to a million of miles, § 47. *M* is the moon, whose centre is $\frac{24}{100}$ parts of an inch from the earth's in this machine, this being in just proportion to the Moon's distance from the Earth, § 52. *AA* is a bar of wood, to be moved by hand round the axis *g*, which is fixed in the wheel *Y*. The circumference of this wheel is to the circumference of the small wheel *L* (below the other end of the bar) as 365¼ days is to 29½; or as a year is to a lunation. The wheels are grooved round their edges, and in the grooves is the cat-gut string *GG* crossing between the wheels at *X*. On the axis of the wheel *L* is the index *F*; in which is fixed the moon's axis *M* for carrying her round the earth *E* (fixed on the axis of the wheel *L*) in the time that the index goes round a circle of 29½ equal parts, which are the days of the Moon's age. The wheel *Y* has the months and days of the year all round its limb; and in the bar *AA* is fixed the index *I*, which points out the days of the months answering to the days of the moon's age shewn by the index *F*, in the circle of 29½ equal parts, at the other end of the bar. On the axis of the wheel *L* is put the piece *D* below the cock *C*, in which this axis turns round; and in *D* are put the pencils *e* and *m*, directly under the earth *E* and moon *M*; so that *m* is carried round *e*, as *M* is round *E*. PLATE VII. Fig. V.

Lay the machine on an even floor, pressing gently on the wheel *Y*, to cause its spiked feet (of which two appear at *P* and *P*, the third being supposed to be hid from sight by the wheel) to enter a little into the floor to secure the wheel from turning. Then lay a paper about four feet long under the pencils *e* and *m*, cross-wise to the bar: which done move the bar slowly round the axis *g* of the wheel *Y*; and, as the earth *E* goes round the sun *S*, the moon *M* will go round the earth with a duly pro- Its use.

portioned velocity; and the friction-wheel *W* running on the floor, will keep the bar from bearing too heavily on the pencils *e* and *m*, which will delineate the paths of the earth and moon, as in Fig. 2d, already described at large, § 266, 267. As the index *I* points out the days of the months, the index *F* shews the Moon's age on these days in the circle of 29½ equal parts. And as this last index points to the different days in its circle, the like numeral figures may be set to those parts of the curves of the earth's path and moon's, where the pencils *e* and *m* are at those times respectively, to shew the places of the earth and moon. If the pencil *e* be pushed a very little off, as if from the pencil *m*, to about $\frac{1}{40}$ part of their distance, and the pencil *m* pushed as much toward *e* to bring them to the same distance again, though not to the same points of space, then as *m* goes round *e*, *e* will go as it were round the centre of gravity between the earth *e* and moon *m*, § 298: but this motion will not sensibly alter the figure of the earth's path or the moon's.

If a pin, as *p*, be put through the pencil *m*, with its head toward that of the pin *q* in the pencil *e*, the head of the former will always keep to the head of the latter as *m* goes round *e*, and shews that the same side of the Moon is continually turned to the Earth. But the pin *p*, which may be considered as an equatorial diameter of the moon will turn quite round the point *m*, making all possible angles with the line of its progress, or line of the moon's path. This is an ocular proof of the Moon's turning round her axis.

The TIDE-DIAL. *Plate IX,* Fig. VII.

404. The TIDE-DIAL. The outside parts of this machine consist of, 1. An eight-sided box, on the top, of which at the corners is shewn the phases of the Moon at the octants, quarters, and full. Within these is a circle of 29½ equal parts, which are the days of the Moon's age accounted from the Sun at new Moon, round to the Sun again. Within

this circle is one of 24 hours divided into their respective halves and quarters. 2. A moving elliptical plate, painted blue, to represent the rising of the tides under and opposite to the Moon; and having the words, *High Water*, *Tide Falling*, *Low Water*, *Tide Rising*, marked upon it. To one end of this plate is fixed the moon *M*, by the wire *W*, and goes along with it. 3. Above this elliptical plate is a round one, with the points of the compass upon it, and also the names of above 200 places in the large machine (but only 32 in the figure, to avoid confusion) set over those points on which the Moon bears when she raises the tides to the greatest heights, at these places, twice in every lunar day: and to the north and south points of this plate are fixed two indexes, *I* and *K*, which shew the times of high water, in the hour-circle, at all these places. 4. Below the elliptical plate are four small plates, two of which project out from below its ends at new and full Moon; and so, by lengthening the ellipse, shew the spring-tides, which are then raised to the greatest heights by the united attractions of the Sun and Moon, § 302. The other two of these small plates appear at low water when the Moon is in her quadratures, or at the sides of the elliptical plate to shew the neap-tides; the Sun and Moon then acting cross-wise to each other. When any two of these small plates appear, the other two are hid; and when the Moon is in her octants, they all disappear, there being neither spring nor neap-tides at those times. Within the box are a few wheels for performing these motions by the handle or winch *H*. Its use.

Turn the handle until the moon *M* comes to any given day of her age in the circle of 29½ equal parts, and the moon's wire *W*, will cut the time of her coming to the meridian on that day, in the hour circle; the XII under the sun being mid-day, and the opposite XII midnight; then looking for the name of any given place on the round plate

(which makes 29½ rotations while the moon *M* makes only one revolution from the sun to the sun again) turn the handle till *that* place comes to the word *High Water* under the moon, and the index which falls among the forenoon-hours will shew the time of high water at that place in the forenoon of the given day: then turn the plate half round, till the same place comes to the opposite high-water-mark, and the index will shew the time of high water in the afternoon at that place. And thus, as all the different places come successively under and opposite to the moon, the indexes shew the times of high water at them in both parts of the day: and when the same places come to the low-water-marks, the indexes shew the times of low water. For about three days before and after the times of new and full Moon, the two small plates come out a little way from below the high-water-marks on the elliptical plate, to shew that the tides rise still higher about these times: and about the quarters, the other two plates come out a little from under the low-water-marks toward the sun and on the opposite side, shewing that the tides of flood rise not then so high, nor do the tides of ebb fall so low, as at other times.

By pulling the handle a little way outward, it is disengaged from the wheel work, and then the upper plate may be turned round quickly by hand, so that the moon may thus be brought to any given day of her age in about a quarter of a minute: and by pushing in the handle, it takes hold of the wheel-work again.

The inside work described. On *AB*, the axis of the handle *H*, is an endless screw *C*, which turns the wheel *FED* of 24 teeth round in 24 revolutions of the handle: this wheel turns another *ONG*, of 48 teeth, and on its axis

Plate IX. Fig. VIII. is the pinion *PQ* of four leaves, which turns the wheel *LKI* of 59 teeth round in 29½ turnings or rotations of the wheel *FED*, or in 708 revolu-

tions of the handle, which is the number of hours in a synodical revolution of the Moon. The round plate with the names of places upon it is fixed on the axis of the wheel *FED;* and the elliptical or tide-plate with the moon fixed to it is upon the axis of the wheel *LKI;* consequently, the former makes $29\frac{1}{2}$ revolutions in the time that the latter makes one. The whole wheel *FED*, with the endless screw *C*, and dotted part of the axis of the handle *AB*, together with the dotted part of the wheel *ONG*, lie hid below the large wheel *LKI*.

Fig. IXth represents the under side of the elliptical or tide-plate *abcd*, with the four small plates *ABCD*, *EFGH*, *IKLM*, *NOPQ*, upon it: each of which has two slits, as *TT*, *SS*, *RR*, *UU*, sliding on two pins, as *nn*, fixed in the elliptical plate. In the four small plates are fixed four pins, at *W*, *X*, *Y*, and *Z;* all of which work in an elliptic groove *oooo* on the cover of the box below the elliptical plate; the longest axis of this groove being in a right line with the sun and full moon. Consequently, when the moon is in conjunction or opposition, the pins *W* and *X* thrust out the plates *ABCD* and *IKLM* a little beyond the ends of the elliptical plate at *d* and *b*, to *f* and *e;* while the pins *Y* and *Z* draw in the plates *EFGH* and *NOPQ* quite under the elliptic plate to *g* and *h*. But, when the moon comes to her first or third quarter, the elliptic plate lies across the fixed elliptic groove in which the pins work; and therefore the end-plates *ABCD* and *IKLM* are drawn in below the great plate, and the other two plates *EFGH* and *NOPQ* are thrust out beyond it to *a* and *c*. When the moon is in her octants, the pins *V*, *X*, *Y*, *Z* are in the parts *o*, *o*, *o*, *o* of the elliptic groove, which parts are at a mean between the greatest and least distances from the centre *q*, and then all the four small plates disappear, being hid by the great one.

The ECLIPSAREON, *Plate XIII.*

405. The ECLIPSAREON. This piece of mechanism exhibits the time, quantity, duration, and progress of solar eclipses, at all parts of the Earth. The principal parts of this machine are, 1. A terrestrial globe *A*, turned round its axis *B*, by the handle or winch *M*; the axis *B* inclines 23½ degrees, and has an index which goes round the hour-circle *D* in each rotation of the globe. 2. A circular plate *E*, on the limb of which the months and days of the year are inserted. This plate supports the globe, and gives its axis the same position to the Sun, or to a candle properly placed, that the Earth's axis has to the Sun upon any day of the year, § 338, by turning the plate till the given day of the month comes to the fixed pointer, or annual index *G*. 3. A crooked wire *F*, which points toward the middle of the Earth's enlightened disc at all times, and shews to what place of the Earth the Sun is vertical at any given time. 4. A penumbra, or thin circular plate of brass *I*, divided into 12 digits by 12 concentric circles, which represent a section of the Moon's penumbra, and is proportioned to the size of the globe; so that the shadow of this plate, formed by the Sun or a candle placed at a convenient distance, with its rays transmitted through a convex lens to make them fall parallel on the globe, covers exactly all those places upon it that the Moon's shadow and penumbra do on the Earth; so that the phenumena of any solar eclipse may be shewn by this machine with candle-light almost as well as by the light of the Sun. 5. An upright frame *HHHH*, on the sides of which are scales of the Moon's latitude or declination from the ecliptic. To these scales are fitted two sliders *K* and *K*, with indexes for adjusting the penumbra's centre to the Moon's latitude, as it is north or south ascending or descending. 6. A solar horizon *C*, dividing the

enlightened hemisphere of the globe from that which is in the dark at any given time, and shewing at what places the general eclipse begins and ends with the rising or setting Sun. 7. A handle *M*, which turns the globe round its axis by wheel-work, and at the same time moves the penumbra across the frame by threads over the pulleys *L*, *L*, *L*, with a velocity duly proportioned to that of the Moon's shadow over the Earth, as the earth turns on its axis. And as the Moon's motion is quicker or slower according to her different distances from the Earth, the penumbral motion is easily regulated in the machine by changing one of the pulleys.

To rectify the machine for use. The true time of new Moon and her latitude being known by the foregoing precepts, § 353, *et seq.* if her latitude exceed the number of minutes or divisions on the scales (which are on the side of the frame hid from view in the figure of the machine) there can be no eclipse of the Sun at that conjunction; but if it do not, the Sun will be eclipsed to some places of the Earth; and, to shew the times and various appearances of the eclipse at those places, proceed in order as follows. To rectify it.

To rectify the machine for performing by the light of the Sun. 1. Move the sliders *K*, *K*, till their indexes point to the Moon's latitude on the scales, as it is north or south ascending or descending, at that time. 2. Turn the month-plate *E* till the day of the given new Moon comes to the annual index *G*. 3. Unscrew the collar *N* a little on the axis of the handle, to loosen the contiguous socket on which the threads that move the penumbra are wound, and set the penumbra by hand till its centre comes to the perpendicular thread in the middle of the frame; which thread represents the axis of the ecliptic. 4. Turn the handle till the meridian of *London* on the globe comes just under the point of the crooked wire *F*; then stop, and turn the hour-circle *D* by hand till XII at noon

comes to its index, and set the penumbra's middle to the thread. 5. Turn the handle till the hour-index points to the time of new Moon in the circle *D*; and holding it there, screw fast the collar *N*. Lastly, elevate the machine till the Sun shines through the sight-holes in the small upright plates *O*, *O*, on the pedestal; and the whole machine will be rectified.

To rectify the machine for shewing by candle-light. Proceed in every respect as above, except in that part of the last paragraph where the Sun is mentioned; instead of which, place a candle before the machine, about four yards from it, so that the shadow of intersection of the cross threads in the middle of the frame may fall precisely on that part of the globe to which the crooked wire *F* points; then, with a pair of compasses, take the distance between the penumbra's centre and intersection of the threads; and equal to that distance set the candle higher or lower, as the penumbra's centre is above or below the said intersection. Lastly, place a large convex lens between the machine and candle, so as that the candle may be in the focus of the lens, and then the rays will fall parallel, and cast a strong light on the globe.

Its use. These things being done, (and they may be done sooner than they can be expressed) turn the handle backward, until the penumbra almost touches the side *HF* of the frame; then turning gradually forward, observe the following phænomena. 1. Where the eastern edge of the shadow of the penumbral plate *I* first touches the globe at the solar horizon: those who inhabit the corresponding part of the Earth see the eclipse begin on the uppermost edge of the Sun, just at the time of its rising. 2. In that place where the penumbra's centre first touches the globe, the inhabitants have the Sun rising upon them centrally eclipsed. 3. When the whole penumbra just falls upon the globe, its western edge at the solar horizon touches and leaves the place where

the eclipse ends at Sun-rise on the lowermost edge. Continue turning; and, 4. the cross lines in the centre of the penumbra will go over all those places on the globe where the Sun is centrally eclipsed. 5. When the eastern edge of the shadow touches any place of the globe, the eclipse begins there; when the vertical line in the penumbra comes to any place, then is the greatest obscuration at that place; and when the western edge of the penumbra leaves the place, the eclipse ends there; the times of all which are shewn on the hour-circle; and from the beginning to the end, the shadows of the concentric penumbral circles shew the number of digits eclipsed at all the intermediate times. 6. When the eastern edge of the penumbra leaves the globe at the solar horizon *C*, the inhabitants see the Sun beginning to be eclipsed on his lowermost edge at its setting. 7. Where the penumbra's centre leaves the globe, the inhabitants see the Sun set centrally eclipsed. And lastly, where the penumbra is wholly departing from the globe, the inhabitants see the eclipse ending on the uppermost part of the Sun's edge, at the time of its disappearing in the horizon.

N. B. If any given day of the year on the plate *E* be set to the annual-index *G*, and the handle turned till the meridian of any place comes under the point of the crooked wire, and then the hour-circle *D* set by the hand till XII comes to its index; in turning the globe round by the handle, when the said place touches the eastern edge of the hoop or solar horizon *C*, the index shews the time of Sun-setting at that place; and when the place is just coming out from below the other edge of the hoop *C*, the index shews the time when the evening-twilight ends to it. When the place has gone through the dark part *A*, and comes about so as to touch under the back of the hoop *C*, on

the other side, the index shews the time when the morning-twilight begins; and when the same place is just coming out from below the edge of the hoop next the frame, the index points out the time of Sun-rising. And thus, the times of the Sun's rising and setting are shewn at all places in one rotation of the globe, for any given day of the year: and the point of the crooked wire *F* shews all the places over which the Sun passes vertically on that day.

A PLAIN METHOD

OF FINDING THE

DISTANCES OF ALL THE PLANETS FROM THE SUN,

BY THE

TRANSIT OF VENUS OVER THE SUN'S DISC, IN THE YEAR 1761.

TO WHICH IS SUBJOINED,

AN ACCOUNT OF MR. HORROX's OBSERVATIONS OF THE TRANSIT OF VENUS IN THE YEAR 1639:

AND ALSO,

OF THE DISTANCES OF ALL THE PLANETS FROM THE SUN, AS DEDUCED FROM OBSERVATIONS OF THE TRANSIT IN THE YEAR 1761.

THE METHOD

OF FINDING

THE DISTANCES OF THE PLANETS FROM THE SUN.

CHAPTER XXIII.

ARTICLE I.

Concerning parallaxes, and their use in general.

1. THE* approaching transit of Venus over the Sun has justly engaged the attention of astronomers, as it is a phenomenon seldom seen, and as the parallaxes of the Sun and planets, and their distances from one another, may be found with greater accuracy by it, than by any other method yet known.

2. The parallax of the Sun, Moon, or any planet, is the distance between its true and apparent place in the heavens. The true place of any celestial object, referred to the starry heaven, is that in which it would appear if seen from the centre of the Earth; the apparent place is that in which it appears as seen from the Earth's surface.

To explain this, let *ABDH* be the Earth (Fig. I. of Plate XIV.), *C* its centre, *M* the Moon, and *ZXR* an arc of the starry heaven. To an observer at *C* (supposing the Earth to be transparent) the Moon *M* will appear at *U*, which is her true place,

* The whole of this Dissertation was published in the beginning of the year 1761, before the time of the transit, except the 7th and 8th articles, which are added since that time.

referred to the starry firmament: but at the same instant, to an observer at *A*, she will appear at *u*, below her true place among the stars.—The angle *AMC* is called the Moon's parallax, and is equal to the opposite angle *UMu*, whose measure is the celestial arc *Uu*.—The whole earth is but a point if compared with its distance from the fixed stars, and therefore we consider the stars as having no parallax at all.

3. The nearer the object is to the horizon, the greater is its parallax; the nearer it is to the zenith, the less. In the horizon it is greatest of all; in the zenith it is nothing.—Thus let *ALt* be the sensible horizon of an observer at *A*; to him the Moon at *L* is in the horizon, and her parallax is the angle *ALC*, under which the Earth's semidiameter *AC* appears as seen from her. This angle is called the Moon's horizontal parallax, and is equal to the opposite angle *TLt*, whose measure is the arc *Tt* in the starry heaven. As the Moon rises higher and higher to the points *M*, *N*, *O*, *P*, in her diurnal course, the parallactic angles *UMu*, *XNx*, *Yoy* diminish, and so do the arcs *Uu*, *Xx*, *Yy*, which are their measures, until the Moon comes to *P*; and then she appears in the zenith *Z* without any parallax, her place being the same whether it be seen from *A* on the Earth's surface, or from *C* its centre.

4. If the observer at *A* could take the true measure or quantity of the parallactic angle *ALC*, he might by that means find the Moon's distance from the centre of the Earth. For, in the plane triangle *LAC*, the side *AC*, which is the Earth's semidiameter, the angle *ALC*, which is the Moon's horizontal parallax, and the right angle *CAL*, would be given. Therefore, by trigonometry, as the tangent of the parallactic angle *ALC* is to radius, so is the Earth's semidiameter *AC* to the Moon's distance *CL* from the Earth's centre *C*.—But because we consider the Earth's semidiameter as unity, and the logarithm of unity is nothing, sub-

tract the logarithmic tangent of the angle *ALC* from radius, and the remainder will be the logarithm of *CL*. and its corresponding number is the number of semi-diameters of the Earth which the Moon is distant from the Earth's centre.—Thus, supposing the angle *ALC* of the Moon's horizontal parallax to be 57′ 18″,

From the radius	—	10.0000000
Subtract the tangent of 57′ 18″		8.2219207
And there will remain	—	1.7780793

which is the logarithm of 59.99, the number of semi-diameters of the Earth which are equal to the Moon's distance from the Earth's centre. Then, 59.99 being multiplied by 3985, the number of miles contained in the Earth's semidiameter, will give 239060 miles for the Moon's distance from the centre of the Earth, by this parallax.

5. But the true quantity of the Moon's horizontal parallax cannot be accurately determined by observing the Moon in the horizon, on account of the inconstancy of the horizontal refractions, which always vary according to the state of the atmosphere; and at a mean rate, elevate the Moon's apparent place near the horizon half as much as her parallax depresses it. And therefore to have her parallax more accurate, astronomers have thought of the following method, which seems to be a very good one, but hath not yet been put in practice.

Let two observers be placed under the same meridian, one in the northern hemisphere, and the other in the southern, at such a distance from each other, that the arc of the celestial meridian included between their two zeniths may be at least 80 or 90 degrees. Let each observer take the distance of the Moon's centre from his zenith, by means of an exceeding good instrument, at the moment of her passing the meridian: add these two zenith-distances of the Moon together, and their excess above the

distance between the two zeniths will be the distance between the two apparent places of the Moon. Then, as the sum of the natural sines of the two zenith distances of the Moon is to radius, so is the distance between her two apparent places to her horizontal parallax: which being found, her distance from the Earth's centre may be found by the analogy mentioned in § 4.

Thus, in Fig. 2. let *VECQ* be the Earth, *M* the Moon, and *Zbaz* an arc of the celestial meridian. Let *V* be *Vienna*, whose latitude *EV* is 48° 20′ north; and *C* the *Cape of Good Hope*, whose latitude *EC* is 34° 30′ south: both which latitudes we suppose to be accurately determined before-hand by the observers. As these two places are on the same meridian *nVECs*, and in different hemispheres, the sum of their latitudes 82° 50′ is their distance from each other. *Z* is the zenith of *Vienna*, and *z* the zenith of the *Cape of Good Hope;* which two zeniths are also 82° 50′ distant from each other, in the common celestial meridian *Zz*. To the observer at *Vienna*, the Moon's centre will appear at *a* in the celestial meridian; and at the same instant, to the observer at the *Cape* it will appear at *b*. Now suppose the Moon's distance *Za* from the zenith of *Vienna* to be 38° 1′ 53″; and her distance *zb* from the zenith of the *Cape of Good Hope* to be 46° 4′ 41″: the sum of these two zenith-distances *(Za+zb)* is 84° 6′ 34″, from which subtract 82° 50′, the distance *Zz* between the zeniths of these two places, and there will remain 1° 16′ 34″ for the arc *ba*, or distance between the two apparent places of the Moon's centre as seen from *V* and from *C*. Then, supposing the tabular radius to be 10000000, the natural sine of 38° 1′ 53″ (the arc *Za)* is 6160816, and the natural sine of 46° 4′ 41″ (the arc *Zb)* is 7202821; the sum of both these sines is 13363637. Say, therefore, As 13363637

is to 10000000, so is 1° 16′ 34″ to 47′ 18″, which is the Moon's horizontal parallax.

If the two places of observation be not exactly under the same meridian, their difference of longitude must be accurately taken, that proper allowance may be made for the Moon's change of declination while she is passing from the meridian of the one to the meridian of the other.

6. The Earth's diameter, as seen from the Moon, subtends an angle of double the Moon's horizontal parallax; which being supposed (as above) to be 57′ 18″, or 3438″, the Earth's diameter must be 1° 54′ 36″, or 6876″. When the Moon's horizontsl parallax (which is variable on account of the eccentricity of her orbit) is 57′ 18″, her diameter subtends an angle of 31′ 2″, or 1862″: therefore the Earth's diameter is to the Moon's diameter, as 6876 is to 1862; that is, as 3.69 is to 1.

And since the relative bulks of spherical bodies are as the cubes of their diameters, the Earth's bulk is to the Moon's bulk, as 49.4 is to 1.

7. The parallax, and consequently the distance and bulk of any primary planet, might be found in the above manner, if the planet were near enough to the Earth, to make the difference of its two apparent places sufficiently sensible: but the nearest planet is too remote for the accuracy required. In order therefore to determine the distances and relative bulks of the planets with any tolerable degree of precision, we must have recourse to a method less liable to error: and this the approaching transit of Venus over the Sun's disc will afford us.

8. From the time of any inferior conjunction of the Sun and Venus to the next, is 583 days 22 hours 7 minutes. And if the plane of Venus's orbit were coincident with the plane of the ecliptic, she would pass directly between the Earth and the Sun at each inferior conjunction, and would then appear like a dark round spot on the Sun for about

7 hours and 3 quarters. But Venus's orbit (like the Moon's) only intersects the ecliptic in two opposite points called its *nodes*. And therefore one half of it is on the north side of the ecliptic, and the other on the south: on which account Venus can never be seen on the Sun, but at those inferior conjunctions which happen in or near the nodes of her orbit. At all the other conjunctions, she either passes above or below the Sun; and her dark side being then toward the Earth, she is invisible.—The last time when this planet was seen like a spot on the Sun, was on the 24th of *November*, old style, in the year 1639.

ARTICLE II.

Shewing how to find the horizontal parallax of Venus by observation, and from thence, by analogy, the parallax and distance of the Sun, and of all the planets from him.

9. In Fig. 4. of Plate XIV. let *DBA* be the Earth, *V* Venus, and *TSR* the eastern limb of the Sun. To an observer at *B* the point *t* of that limb will be on the meridian, its place referred to the heaven will be at *E*, and Venus will appear just within it at *S*. But, at the same instant, to an observer at *A*, Venus is east of the Sun, in the right line *AVF*; the point *t* of the Sun's limb appears at *e* in the heavens, and if Venus were then visible, she would appear at *F*. The angle *CVA* is the horizontal parallax of Venus, which we seek; and is equal to the opposite angle *FVE*, whose measure is the arc *FE*. *ASC* is the Sun's horizontal parallax, equal to the opposite angle *eSE*, whose measure is the arc *eE*: and *FAe* (the same as *VAv*) is Venus's horizontal parallax from the Sun, which may be found by observing how much later in absolute time her total ingress on the Sun is, as seen from *A*, than as seen from *B*, which is the

time she takes to move from *V* to *v* in her orbit *OVv*.

10. It appears by the tables of Venus's motion and the Sun's, that at the time of her ensuing transit, she will move 4′ of a degree on the Sun's disc in 60 minutes of time; and therefore she will move 4″ of a degree in one minute of time.

Now let us suppose, that *A* is 90° west of *B*, so that when it is noon at *B*, it will be VI in the morning at *A*; that the total ingress as seen from *B* is at 1 minute past XII, but that as seen from *A* it is at 7 minutes 30 seconds past VI: deduct 6 hours for the difference of meridians of *A* and *B*, and the remainder will be 6 minutes 30 seconds for the time by which the total ingress of Venus on the Sun at *S* is later as seen from *A* than as seen from *B*: which time being converted into parts of a degree is 26″, or the arc *Fe* of Venus's horizontal parallax from the Sun: for, as 1 minute of time is to 4 seconds of a degree, so is 6½ minutes of time to 26 seconds of a degree.

11. The times in which the planets perform their annual revolutions about the Sun, are already known by observation.—From these times, and the universal power of gravity by which the planets are retained in their orbits, it is demonstrable, that if the Earth's mean distance from the Sun be divided into 100000 equal parts, Mercury's mean distance from the Sun must be equal to 38710 of these parts—Venus's mean distance from the Sun, to 72333—Mars's mean distance, 152369—Jupiter's 520096—and Saturn's, 954006. Therefore, when the number of miles contained in the mean distance of any planet from the Sun is known, we can, by these proportions, find the mean distance in miles of all the rest.

12. At the time of the ensuing transit, the Earth's distance from the Sun will be 1015 (the mean distance being here considered as 1000), and Venus's distance from the Sun will be 720 (the mean distance

being considered as 723), which differences from the mean distances arise from the elliptical figure of the planets' orbits—Subtract 726 parts from 1015, and there will remain 289 parts for Venus's distance from the earth at that time.

13. Now, since the horizontal parallaxes of the planets are* inversely as their distances from the Earth's centre, it is plain, that as Venus will be between the Earth and the Sun on the day of her transit, and consequently her parallax will be then greater than the Sun's, if her horizontal parallax can be on that day ascertained by observation, the Sun's horizontal parallax may be found, and consequently his distance from the Earth.—Thus, suppose Venus's horizontal parallax should be found to be 36″.3480; then, As the Sun's distance 1015 is to Venus's distance 289, so is Venus's horizontal parallax 36″.3480 to the Sun's horizontal parallax 10″.3493, on the day of her transit. And the difference of these two parallaxes, viz. 25″.9987 (which may be esteemed 26″) will be the quantity of Venus's horizontal parallax from the Sun; which is one of the elements for prejecting or delineating her transit over the Sun's disc, as will appear further on.

To find the Sun's horizontal parallax at the time of his mean distance from the Earth, say, As 1000 parts, the Sun's mean distance from the Earth's centre, is to 1015, his distance from it on the

* To prove this, let *S* be the Sun (Fig 3) *V* Venus, *AB* the Earth, *C* its centre, and *AC* its semidiameter The angle *AVC* is the horizontal parallax of Venus, and *ASC* the horizontal parallax of the Sun. But by the property of plane triangles, as the sine of *AVC* (or of *SVA* its supplement to 180) is to the sine of *AVC*, so is *AS* to *AV*, and so is *CS* to *CV*—N B In all angles less than a minute of a degree, the sines, tangents, and arcs, are so nearly equal, that they may, without error be used for one another And here we make use of *Gardiner's* logarithmic tables, because they have the sines to every second of a degree.

day of the transit, so is 10″.3493, his horizontal parallax on that day, to 10″.5045, his horizontal parallax at the time of his mean distance from the Earth's centre.

14. The Sun's parallax being thus (or any other way supposed to be) found, at the time of his mean distance from the Earth, we may find his true distance from it in semidiameters of the Earth, by the following analogy. As the sine (or tangent of so small an arc as that) of the Sun's parallax 10″.5045 is to radius, so is unity, or the Earth's semidiameter, to the number of semidiameters of the Earth that the Sun is distant from its centre, which number, being multiplied by 3985, the number of miles contained in the Earth's semidiameter, will give the number of miles which the Sun is distant from the Earth's centre.

Then, by § 11, As 100000, the Earth's mean distance from the Sun in parts, is to 38710, Mercury's mean distance from the Sun in parts, so is the Earth's mean distance from the Sun in miles to Mercury's mean distance from the Sun in miles.—And,

As 100000 is to 72333, so is the Earth's mean distance from the Sun in miles to Venus's mean distance from the Sun in miles.—Likewise,

As 100000 is to 152369, so is the Earth's mean distance from the Sun in miles to Mars's mean distance from the Sun in miles.—Again,

As 100000 is to 520096, so is the Earth's mean distance from the Sun in miles to Jupiter's mean distance from the Sun in miles.—Lastly,

As 100000 is to 954006, so is the Earth's mean distance from the Sun in miles to Saturn's mean distance from the Sun in miles.

And thus, by having found the distance of any one of the planets from the Sun, we have sufficient *data* for finding the distances of all the rest.—And then from their apparent diameters at these known

distances, their real diameters and bulks may be found.

15. The Earth's diameter, as seen from the Sun, subtends an angle of double the Sun's horizontal parallax, at the time of the Earth's mean distance from the Sun: and the Sun's diameter, as seen from the Earth at that time, subtends an angle of 32′ 2″, or 1922″. Therefore the Sun's diameter is to the Earth's diameter, as 1922 is to 21.—And since the relative bulks of spherical bodies are as the cubes of their diameters, the Sun's bulk is to the Earth's bulk, as 756058 is to 1; supposing the Sun's mean horizontal parallax to be 10″.5, as above.

16. It is plain by Fig. 4. that whether Venus be at *U* or *V*, or in any other part of the right line *BVS*, it will make no difference in the time of her total ingress on the Sun at *S*, as seen from *B;* but as seen from *A* it will. For, if Venus be at *V*, her horizontal parallax from the Sun is the arc *Fe*, which measures the angle *FAe:* but if she be nearer the Earth, as at *U*, her horizontal parallax from the Sun is the arc *fe*, which measures the angle *fAe;* and this angle is greater than the angle *FAe*, by the difference of their measures *fF*. So that, as the distance of the celestial object from the Earth is less, its parallax is the greater.

17. To find the parallax of Venus by the above method, it is necessary, 1. That the difference of meridians of the two places of observation be 90°. —2. That the time of Venus's total ingress on the Sun be when his eastern limb is either on the meridian of one of the places, or very near it.—And, 3. That each observer have his clock exactly regulated to the equal time at his place. But as it might, perhaps, be difficult to find two places on the Earth suited to the first and second of these requisites, we shall shew how this important problem may be solved by a single observer, if he be exact

as to his longitude, and have his clock truly adjusted to the equal time at his place.

18. That part of Venus's orbit in which she will move during her transit on the Sun, may be considered as a straight line; and therefore, a plane may be conceived to pass both through it and the Earth's centre. To every place on the Earth's surface cut by this plane, Venus will be seen on the Sun in the same path that she would describe as seen from the Earth's centre; and therefore she will have no parallax of latitude, either north or south; but will have a greater or less parallax of longitude, as she is more or less distant from the meridian, at any time during her transit.

Matura, a town and fort on the south coast of the island of *Ceylon*, will be in this plane at the time of Venus's total ingress on the Sun; and the Sun will then be $62\frac{1}{2}°$ east of the meridian of that place. Consequently to an observer at *Matura*, Venus will have a considerable parallax of longitude eastward from the Sun, when she would appear to touch the Sun's eastern limb as seen from the Earth's centre, at which the astronomical tables suppose the observer to be placed, and give the times as seen from thence.

19. According to these tables, Venus's total ingress on the Sun will be 50 minutes after VII in the morning, at *Matura**, supposing that place to be 80° east longitude from the meridian of *London*, which is the observer's business to determine. Let us imagine that he finds it to be exactly so, but that to him the total ingress is at VII hours 55 minutes 46 seconds, which is 5 minutes 46 seconds later than the true calculated time of total ingress, as seen from the Earth's centre. Then, as Venus's motion on (or

* The time of total ingress at *London*, as seen from the Earth's centre, is at 30 minutes after II in the morning; and if *Matura* be just 80° (or 5 hours 20 minutes) east of *London*, when it is 30 minutes past II in the morning at *London*, it is 50 minutes past VII at *Matura*.

toward, or from) the Sun is at the rate of 4 minutes of a degree in an hour (by § 10.) her motion must be 23″.1 of a degree in 5 minutes 46 seconds of time: and this 23″.1 is her parallax eastward, from her total ingress as seen from *Matura*, when her ingress would be total if seen from the Earth's centre.

20. At VII hours 50 minutes in the morning, the Sun is 62½° from the meridian; at VI in the morning he is 90° from it: therefore, as the sine of 62½° is to the sine of 23″.1 (which is Venus's parallax from her true place on the Sun at VII hours 50 minutes), so is radius or the sine of 90°, to the sine of 26″, which is Venus's horizontal parallax from the Sun at VI. In logarithms thus:

As the logarithmic sine of 62° 30′ - - -	9.9479289
Is to the logarithmic sine of 23″.1 - - -	6.0481510
So is the logarithmic radius - - -	10.0000000
To the logarithmic sine of 26″ very nearly -	6.1002221

Divide the Sun's distance from the Earth, 1015, by his distance from Venus 726 (§ 12.) and the quotient will be 1.3980; which being multiplied by Venus's horizontal parallax from the Sun 26″, will give 36″.3480, for her horizontal parallax as seen from the Earth at that time.—Then (by § 13.) as the Sun's distance, 1015, is to Venus's distance 289, so is Venus's horizontal parallax 36″.3480 to the Sun's horizontal parallax 10″.3493.—If Venus's horizontal parallax from the Sun be found by observation to be greater or less than 26″, the Sun's horizontal parallax must be greater or less than 10″.3493 accordingly.

21. And thus, by a single observation, the parallax of Venus, and consequently the parallax of the Sun, might be found, if we were sure that the astronomical tables were quite correct as to the time of Venus's total ingress on the Sun.—But although the tables may be safely depended upon for shewing the true

duration of the transit, which will not be quite 6 hours from the time of Venus's total ingress on the Sun's eastern limb, to the beginning of her egress from his western; yet they may perhaps not give the true times of these two internal contacts: like a good common clock, which, though it may be trusted to for measuring a few hours of time, yet perhaps it may not be quite adjusted to the meridian of the place, and consequently not true as to any one hour; which every one knows is generally the case.—Therefore, to make sure work, the observer ought to watch both the moment of Venus's total ingress on the Sun, and her beginning of egress from him, so as to note precisely the times between these two instants, by means of a good clock: and by comparing the interval at his place with the true calculated interval as seen from the Earth's centre, which will be 5 hours 58 minutes, he may find the parallax of Venus from the Sun both at her total ingress and beginning of egress.

22. The manner of observing the transit should be as follows:—The observer being provided with a good telescope, and a pendulum-clock well adjusted to the mean diurnal revolution of the Sun, and as near to the time at his place as conveniently may be; and having an assistant to watch the clock at the proper times, he must begin to observe the Sun's eastern limb through his telescope, twenty minutes at least before the computed time of Venus's total ingress upon it, lest there should be an error in the time of the beginning as given by the tables.

When he perceives a dent (as it were) to be made in the Sun's limb, by the interposition of the dark body of Venus, he must then continue to watch her through the telescope as the dent increases; and his assistant must watch the time shewn by the clock, till the whole body of the planet appears just within the Sun's limb: and the moment when the bright limb of the Sun appears close by the east side of the

dark limb of the planet, the observer, having a little hammer in his hand, is to strike a blow therewith on the table or wall; the moment of which, the assistant notes by the clock, and writes it down.

Then, let the planet pass on for about 2 hours 59 minutes, in which time it will be got to the middle of its apparent path on the Sun, and consequently will then be at its least apparent distance from the Sun's centre; at which time, the observer must take its distance from the Sun's centre by means of a good micrometer, in order to ascertain its true latitude or declination from the ecliptic, and thereby find the places of its nodes.

This done, there is but little occasion to observe it any longer, until it comes so near the Sun's western limb, as almost to touch it. Then the observer must watch the planet carefully with his telescope: and his assistant must watch the clock, so as to note the precise moment of the planet's touching the Sun's limb, which the assistant knows by the observer striking a blow with his hammer.

23. The assistant must be very careful in observing what minute on the dial-plate the minute-hand has past, when he has observed the second-hand at the instant the blow was struck by the hammer; otherwise, though he be right as to the number of seconds of the current minute, he may be liable to make a mistake in the number of minutes.

24. To those places where the transit begins before XII at noon, and ends after it, Venus will have an eastern parallax from the Sun at the beginning, and a western parallax from the Sun at the end; which will contract the duration of the transit, by causing it to begin later and end sooner, at these places, than it does as seen from the Earth's centre; which may be explained in the following manner.

In Fig. 5. of Plate XIV let *BMA* be the Earth, *V* Venus, and *S* the Sun. The Earth's motion on its axis from west to east, or in the direction *AMB*, carries an observer on that side contrary to the motion of Venus in her orbit, which is in the direction *UVW;* and will therefore cause her motion to appear quicker on the Sun's disc, than it would appear to an observer placed at the Earth's centre *C*, or at either of its poles. For, if Venus were to stand still in her orbit at *V* for twelve hours, the observer on the Earth's surface would in that time be carried from *A* to *B*, through the arc *AMB*. When he was at *A*, he would see Venus on the Sun at *R;* when at *M*, he would see her at *S;* and when he was at *B*, he would see her at *T:* so that his own motion would cause the planet to appear in motion on the Sun through the line *RST;* which being in the direction of her apparent motion on the Sun as she moves in her orbit *UW*, her motion will be accelerated on the Sun to this observer, just as much as his own motion would shift her apparent place on the Sun, if she were at rest in her orbit at *V*.

But as the whole duration of the transit, from first to last internal contact, will not be quite six hours; an observer, who has the Sun on his meridian at the middle of the transit, will be carried only from *a* to *b* during the whole time thereof. And therefore, the duration will be much less contracted by his own motion, than if the planet were to be twelve hours in passing over the Sun, as seen from the Earth's centre.

25. The nearer Venus is to the Earth, the greater is her parallax, and the more will the true duration of her transit be contracted thereby; the farther she is from the Earth, the contrary: so that the contraction will be in direct proportion to the parallax. Therefore, by observing, at proper places, how much the duration of the transit is less than its true duration at the Earth's centre, where it is 5 hours 58 minutes,

as given by the astronomical tables, the parallax of Venus will be ascertained.

26. The above method (§ 17, & *seq.*) is much the same as was prescribed long ago by Doctor Halley; but the calculations differ considerably from his; as will appear in the next article, which contains a translation of the Doctor's whole dissertation on that subject.--He had not computed his own tables when he wrote it, nor had he time before-hand to make a sufficient number of observations on the motion of Venus, so as to determine whether the nodes of her orbit are at rest or not; and was therefore obliged to trust to other tables, which are now found to be erroneous.

ARTICLE III.

Containing Doctor HALLEY'S *Dissertation on the method of finding the Sun's parallax and distance from the Earth, by the transit of Venus over the Sun's disc,* June *the 6th,* 1761. *Translated from the Latin in* Mottee's *Abridgment of the Philosophical Transactions, Vol. I. page* 243; *with additional notes.*

There are many things exceedingly paradoxical, and that seem quite incredible to the illiterate, which yet by means of mathematical principles may be easily solved. Scarce any problem will appear more hard and difficult, than that of determining the distance of the Sun from the Earth very near the truth: but even this, when we are made acquainted with some exact observations, taken at places fixed upon, and chosen before-hand, will without much labour be effected. And this is what I am now desirous to lay before this illustrious Society* (which I foretel will continue for ages), that I may explain before-hand to young astronomers, who may perhaps live to observe these things,

* The Royal Society.

a method by which the immense distance of the Sun may be truly obtained, to within a five-hundredth part of what it really is.

It is well known that the distance of the Sun from the Earth is by different astronomers supposed different, according to what was judged most probable from the best conjecture that each could form. *Ptolemy* and his followers, as also *Copernicus* and *Tycho Brahe*, thought it to be 1200 semidiameters of the Earth; *Kepler*, 3500 nearly: *Ricciolus* doubles the distance mentioned by *Kepler;* and *Hevelius* only increases it by one half. But the planets Venus and Mercury having, by the assistance of the telescope, been seen on the disc of the Sun, deprived of their borrowed brightness, it is at length found that the apparent diameters of the planets are much less than they were formerly supposed; and that the semidiameter of Venus seen from the Sun subtends an angle of no more than a fourth part of a minute, or 15 seconds, while the semidiameter of Mercury, at its mean distance from the Sun, is seen under an angle only of ten seconds; that the semidiameter of Saturn seen from the Sun appears under the same angle; and that the semidiameter of Jupiter, the largest of all the planets, subtends an angle of no more than a third part of a minute at the Sun. Whence, keeping the proportion, some modern astronomers have thought, that the semidiameter of the Earth, seen from the Sun, would subtend a mean angle between that larger one subtended by Jupiter, and that smaller one subtended by Saturn and Mercury; and equal to that subtended by Venus (namely, fifteen seconds): and have thence concluded, that the Sun is distant from the Earth almost 14000 of the Earth's semidiameters. But the same authors have on another account somewhat increased this distance: for inasmuch as the Moon's diameter is a little more than a fourth part of the diameter of the Earth, if the Sun's parallax should be supposed

fifteen seconds, it would follow that the body of the Moon is larger than that of Mercury; that is, that a secondary planet would be greater than a primary; which would seem inconsistent with the uniformity of the mundane system. And on the contrary, the same regularity and uniformity seems scarcely to admit that Venus, an inferior planet, that has no satellite, should be greater than our Earth, which stands higher in the system, and has such a splendid attendant. Therefore, to observe a mean, let us suppose the semidiameter of the Earth seen from the Sun, or, which is the same thing, the Sun's horizontal parallax, to be twelve seconds and a half; according to which, the Moon will be less than Mercury, and the Earth larger than Venus; and the Sun's distance from the Earth will come out nearly 16,500 of the Earth's semidiameters. This distance I assent to at present, as the true one, till it shall become certain what it is, by the experiment which I propose. Nor am I induced to alter my opinion by the authority of those (however weighty it may be) who are for placing the Sun at an immense distance beyond the bounds here assigned, relying on observations made upon the vibrations of a pendulum, in order to determine those exceeding small angles; but which, as it seems, are not sufficient to be depended upon; at least, by this method of investigating the parallax, it will sometimes come out nothing, or even negative; that is, the distance would either become infinite, or greater than infinite; which is absurd. And indeed, to confess the truth, it is hardly possible for a man to distinguish, with any degree of certainty, seconds, or even ten seconds, with instruments, let them be ever so skilfully made: therefore, it is not at all to be wondered at, that the excessive nicety of this matter has eluded the many and ingenious endeavours of such skilful operators.

About forty years ago, while I was in the island of *St. Helena*, observing the stars about the south

pole, I had an opportunity of observing, with the greatest diligence, Mercury passing over the disc of the Sun; and (which succeeded better than I could have hoped for) I observed, with the greatest degree of accuracy, by means of a telescope 24 feet long, the very moment when Mercury entering upon the Sun seemed to touch its limb within, and also the moment when going off it struck the limb of the Sun's disc, forming the angle of interior contact: whence I found the interval of time, during which Mercury then appeared within the Sun's disc, even without an error of one second of time. For the lucid line intercepted between the dark limb of the planet and the bright limb of the Sun, although exceeding fine, is seen by the eye; and the little dent made in the Sun's limb, by Mercury's entering the disc, appears to vanish in a moment; and also that made by Mercury, when leaving the disc, seems to begin in an instant.—When I perceived this, it immediately came into my mind, that the Sun's parallax might be accurately determined by such kind of observations as these; provided Mercury were but nearer to the Earth, and had a greater parallax from the Sun; but the difference of these parallaxes is so little, as always to be less than the solar parallax which we see; and therefore Mercury, though frequently to be seen on the Sun, is not to be looked upon as fit for our purpose.

There remains then the transit of Venus over the Sun's disc; whose parallax, being almost four times as great as the solar parallax, will cause very sensible differences between the times in which Venus will seem to be passing over the Sun at different parts of the Earth. And from these differences, if they be observed as they ought, the Sun's parallax may be determined even to a small part of a second. Nor do we require any other instruments for this purpose, than common telescopes and clocks, only good of their kind: and in the observers, nothing more is needful

than fidelity, diligence, and a moderate skill in astronomy. For there is no need that the latitude of the place should be scrupulously observed, nor that the hours themselves should be accurately determined with respect to the meridian: it is sufficient that the clocks be regulated according to the motion of the heavens, if the times be well reckoned from the total ingress of Venus into the Sun's disc, to the beginning of her egress from it; that is, when the dark globe of Venus first begins to touch the bright limb of the Sun within; which moments, I know, by my own experience, may be observed within a second of time.

But on account of the very strict laws by which the motions of the planets are regulated, Venus is seldom seen within the Sun's disc; and during the course of more than 120 years, it could not be seen once; namely, from the year 1639 (when this most pleasing sight happened to that excellent youth, *Horrox*, our countryman, and to him only, since the creation) to the year 1761; in which year, according to the theories which we have hitherto found agreeable to the celestial motions, Venus will again pass over the Sun on the* 26th of *May*, in the morning; so that at *London*, about six o'clock in the morning, we may expect to see it near the middle of the Sun's disc, and not above four minutes of a degree south of the Sun's centre. But the duration of this transit will be almost eight hours; namely, from two o'clock in the morning till almost ten. Hence the ingress will not be visible in *England*; but as the Sun will at that time be in the 16th degree of Gemini, having almost 23 degrees north declination, it will be seen without setting at all in almost all parts of the north frigid zone: and therefore the inhabitants of the coast of *Norway*, beyond the city of *Nidrosia*, which is called *Drontheim*, as far as the *North Cape*, will be able to observe Venus entering the Sun's disc; and perhaps

* The sixth of *June*, according to the new style.

the ingress of Venus upon the Sun, when rising, will be seen by the *Scotch*, in the northern parts of the kingdom, and by the inhabitants of the *Shetland Isles*, formerly called *Thule*. But at the time when Venus will be nearest the Sun's centre, the Sun will be vertical to the northern shores of the bay of *Bengal*, or rather over the kingdom of *Pegu*; and therefore in the adjacent regions, as the Sun, when Venus enters his disc, will be almost four hours towards the east, and as many toward the west when she leaves him, the apparent motion of Venus on the Sun will be accelerated by almost double the horizontal parallax of Venus from the Sun; because Venus at that time is carried with a retrograde motion from east to west, while an eye placed upon the Earth's surface is whirled the contrary way, from west to east*.

* This has been already taken notice of in § 24; but I shall here endeavour to explain it more at large, together with some of the following part of the Doctor's Essay, by a figure.

In Fig. 1. of Plate XV let *C* be the centre of the Earth, and *Z* the centre of the Sun. In the right line *CeZ*, make *eZ* to *CZ* as 726 is to 1015 (§ 12). Let *acbd* be the Earth, *e* Venus's place in her orbit at the time of her conjunction with the Sun, and let *TvU* be the Sun, whose diameter is 31′ 42″.

The motion of Venus in her orbit is in the direction *Nen*, and the Earth's motion on its axis is according to the order of the 24 hours placed around it in the figure. Therefore, supposing the mouth of the *Ganges* to be at *G*, when Venus is at *E* in her orbit, and to be carried from *G* to *g* by the Earth's motion on its axis, while Venus moves from *E* to *e* in her orbit, it is plain that the motions of Venus and the *Ganges* are contrary to each other.

The true motion of Venus in her orbit, and consequently the space she seems to run over on the Sun's disc in any given time, could be seen only from the Earth's centre *C*, which is at rest with respect to its surface. And as seen from *C*, her path on the Sun would be in the right line *TvU*; and her motion thereon at the rate of four minutes of a degree in an hour. *T* is the point of the Sun's eastern limb which Venus seems to touch at the moment of her total ingress on the Sun, as seen from *C*, when Venus is at *E* in her orbit, and *U* is the point of the Sun's western limb which she seems to touch at the moment of her beginning of egress from the Sun, as seen from *C*, when she is at *e* in her orbit.

Supposing the Sun's parallax (as we have said) to be 12¼″, the parallax of Venus will be 43″; from which subtracting the parallax of the Sun, there will remain 30″ at least for the horizontal parallax of Venus from the Sun; and therefore the motion of Venus will be increased 45″ at least by that parallax, while she passes over the Sun's disc, in those elevations of the pole which are in places near the tropic, and yet more in the neighbourhood of the equator. Now Venus at that time will move on the sun's disc, very nearly at the rate of four minutes of a degree in an hour; and therefore 11 minutes of time at least are to be allowed for 45″, or three fourths of a minute of

When the mouth of the *Ganges* is at *m* (in revolving through the arc *Gmg*) the Sun is on its meridian. Therefore, since *G* and *g* are equally distant from *m* at the beginning and ending of the transit, it is plain that the Sun will be as far east of the meridian of the *Ganges* (at *G*) when the transit begins, as it will be west of the meridian of the same place (revolving from *G* to *g*) when the transit ends.

But although the beginning of the transit, or rather the moment of Venus's total ingress upon the Sun at *T*, as seen from the Earth's centre, must be when Venus is at *E* in her orbit, because she is then seen in the direction of the right line *CET*; yet at the same instant of time, as seen from the *Ganges* at *G*, she will be short of her ingress on the Sun, being then seen eastward of him, in the right line *GEK*, which makes the angle *KET* (equal to the opposite angle *GEC*), with the right line *CET*. This angle is called the angle of Venus's parallax from the Sun, which retards the beginning of the transit as seen from the banks of the *Ganges*; so that the *Ganges G*, must advance a little farther toward *m*, and Venus must move on in her orbit from *E* to *R*, before she can be seen from *G* (in the right line *GRT*) wholly within the Sun's disc at *T*.

When Venus comes to *e* in her orbit, she will appear at *U*, as seen from the Earth's centre *C*, just beginning to leave the Sun; that is, at the beginning of her egress from his western limb: but at the same instant of time, as seen from the *Ganges*, which is then at *g*, she will be quite clear of the Sun toward the west, being then seen from *g* in the right line *geL*, which makes an angle, as *UeL* (equal to the opposite angle *Ceg*), with the right line *CeU*: and this is the angle of Venus's

a degree; and by this space of time, the duration of this eclipse caused by Venus will, on account of the parallax, be shortened. And from this shortening of the time only, we might safely enough draw a conclusion concerning the parallax which we are in search of, provided the diameter of the Sun, and the latitude of Venus, were accurately known. But we cannot expect an exact computation in a matter of such subtilty.

We must endeavour therefore to obtain, if possible, another observation, to be taken in those places where Venus will be in the middle of the Sun's disc at midnight; that is, in places under the opposite meridian to the former, or about 6 hours or 90 degrees west of *London;* and where Venus enters upon the Sun a little before its set-

parallax from the Sun, as seen from the *Ganges* at *g*, when she is but just beginning to leave the Sun at *U*, as seen from the Earth's centre *C*.

Here it is plain, that the duration of the transit about the mouth of the *Ganges* (and also in the neighbouring places) will be diminished by about double the quantity of Venus's parallax from the Sun at the beginning and ending of the transit. For Venus must be at *E* in her orbit when she is wholly upon the Sun at *T*, as seen from the Earth's centre *C*: but at that time she is short of the Sun, as seen from the *Ganges* at *G*, by the whole quantity of her eastern parallax from the Sun at that time, which is the angle *KET* [This angle, in fact, is only 23″, though it is represented much larger in the figure, because the Earth therein is a vast deal too big.] Now, as Venus moves at the rate of 4′ in an hour, she will move 23″ in 5 minutes 45 seconds: and therefore, the transit will begin later by 5 minutes 45 seconds at the banks of the *Ganges* than at the Earth's centre.—When the transit is ending at *U*, as seen from the Earth's centre at *C*, Venus will be quite clear of the Sun (by the whole quantity of her western parallax from him) as seen from the *Ganges*, which is then at *g*: and this parallax will be 22″, equal to the space through which Venus moves in 5 minutes 30 seconds of time: so that the transit will end $5\frac{1}{2}$ minutes sooner as seen from the *Ganges*, than as seen from the Earth's centre.

Here the whole contraction of the duration of the transit at the mouth of the *Ganges* will be 11 minutes 15 seconds of time: for it is 5 minutes 45 seconds at the beginning, and 5 minutes 30 seconds at the end.

ting, and goes off a little after its rising. And this will happen under the above-mentioned meridian, and where the elevation of the north pole is about 56 degrees; that is, in a part of *Hudson's Bay*, near a place called *Port-Nelson*. For, in this and the adjacent places, the parallax of Venus will increase the duration of the transit by at least six minutes of time; because, while the Sun, from its setting to its rising, seems to pass under the pole, those places on the Earth's disc will be carried with a motion from east to west, contrary to the motion of the *Ganges*; that is, with a motion conspiring with the motion of Venus; and therefore Venus will seem to move more slowly on the Sun, and to be longer in passing over his disc.*

* In Fig. I. of Plate XV. let *aC* be the meridian of the eastern mouth of the *Ganges*; and *bC* the meridian of *Port-Nelson* at the mouth of *York River* in *Hudson's Bay*, 56° north latitude. As the meridian of the *Ganges* revolves from *a* to *c*, the meridian of *Port-Nelson* will revolve from *b* to *d*: therefore, while the *Ganges* revolves from *G* to *g*, through the arc *Gmg*, *Port-Nelson* revolves the contrary way (as seen from the Sun or Venus) from *P* to *p* through the arc *Pnp*.——Now, as the motion of Venus is from *E* to *e* in her orbit, while she seems to pass over the Sun's disc in the right line *TU*, as seen from the Earth's centre *C*, it is plain that while the motion of the *Ganges* is contrary to the motion of Venus in her orbit, and thereby shortens the duration of the transit at that place, the motion of *Port-Nelson* is the same way as the motion of Venus, and will therefore increase the duration of the transit: which may in some degree be illustrated by supposing, that while a ship is under sail, if two birds fly along the side of the ship in contrary directions to each other, the bird which flies contrary to the motion of the ship will pass by it sooner than the bird will, which flies the same way that the ship moves.

In fine, it is plain by the figure, that the duration of the transit must be longer as seen from *Port-Nelson*, than as seen from the Earth's centre, and longer as seen from the Earth's centre, than as seen from the mouth of the *Ganges*——For *Port-Nelson* must be at *P*, and Venus at *N* in her orbit, when she appears wholly within the Sun at *T*: and the same place must be at *p*, and Venus at *n*, when she appears at *U* beginning to leave the Sun.—The *Ganges* must be at *G*, and Venus at *R*, when she is seen from *G* upon

If therefore it should happen that this transit should be properly observed by skilful persons at both these places, it is clear, that its duration will be 17 minutes longer, as seen from *Port-Nelson*, than as seen from the *East-Indies*. Nor is it of much consequence (if the *English* shall at that time give any attention to this affair) whether the observation be made at *Fort-George*, commonly called *Madras*, or at *Bencoolen* on the western shore of the island of *Sumatra*, near the equator. But if the *French* should be disposed to take any pains herein, an observer may station himself conveniently enough at *Pondicherry* on the west shore of the bay of *Bengal*, where the altitude of the pole is about 12 degrees. As to the *Dutch*, their celebrated mart at *Batavia* will afford them a place of observation fit enough for this purpose, provided they also have but a disposition to assist in advancing, in this particular, the knowledge of the heavens.—And indeed I could wish that many observations of the same phenomenon might be taken by different persons at several places, both that we might arrive at a greater degree of certainty by their agreement, and also lest any single observer should be deprived, by the intervention of clouds, of a sight, which I know not whether any man living in this or the next age will ever see again; and on which depends the certain and adequate solution of a problem the most noble, and at any other time not to be attained to. I recommend it, therefore, again and again, to those curious astronomers, who (when I am dead) will have an opportunity of observing these things, that they would remem-

the Sun at *T*; and the same place must be at *g*, and Venus at *r*, when she begins to leave the Sun at *U*, as seen from *g*. So that Venus must move from *N* to *n* in her orbit, while she is seen to pass over the Sun from *Port-Nelson*; from *E* to *e* in passing over the Sun, as seen from the Earth's centre; and only from *R* to *r* while she passes over the Sun, as seen from the banks of the *Ganges*.

ber this my admonition, and diligently apply themselves with all their might to the making of this observation; and I earnestly wish them all imaginable success; in the first place, that they may not, by the unseasonable obscurity of a cloudy sky, be deprived of this most desirable sight; and then, that having ascertained with more exactness the magnitudes of the planetary orbits, it may redound to their immortal fame and glory.

We have now shewn, that by this method the Sun's parallax may be investigated to within its five-hundredth part, which doubtless will appear wonderful to some. But if an accurate observation be made in each of the places above marked out, we have already demonstrated that the durations of this eclipse made by Venus will differ from each other by 17 minutes of time; that is, upon a supposition that the Sun's parallax is $12\frac{1}{2}''$. But if the difference shall be found by observation to be greater or less, the Sun's parallax will be greater or less, nearly in the same proportion. And since 17 minutes of time are answerable to $12\frac{1}{2}$ seconds of solar parallax, for every second of parallax there will arise a difference of more than 80 seconds of time; whence, if we have this difference true to two seconds, it will be certain what the Sun's parallax is to within a 40th part of one second; and therefore his distance will be determined to within its 500dth part at least, if the parallax be not found less than what we have supposed: for 40 times $12\frac{1}{2}$ make 500.

And now I think I have explained this matter fully, and even more than I needed to have done, to those who understand astronomy; and I would have them take notice, that on this occasion, I have had no regard to the latitude of Venus, both to avoid the inconvenience of a more intricate calculation, which would render the conclusion less evident; and also because the motion of the nodes

of Venus is not yet discovered, nor can be determined but by such conjunctions of the planet with the Sun as this is. For we conclude that Venus will pass 4 minutes below the Sun's centre, only in consequence of the supposition that the plane of Venus's orbit is immoveable in the sphere of the fixed stars, and that its nodes remain in the same places where they were found in the year 1639. But if Venus in the year 1761, should move over the Sun in a path more to the south, it will be manifest that her nodes have moved backward among the fixed stars; and if more to the north, that they have moved forward; and that at the rate of 5¼ minutes of a degree in 100 Julian years, for every minute that Venus's path shall be more or less distant than the above-said 4 minutes from the Sun's centre. And the difference between the duration of these eclipses will be somewhat less than 17 minutes of time, on account of Venus's south latitude; but greater, if by the motion of the nodes forward she should pass on the north of the Sun's centre.

But for the sake of those who, though they are delighted with sidereal observations, may not yet have made themselves acquainted with the doctrine of parallaxes, I choose to explain the thing a little more fully by a scheme, and also by a calculation somewhat more accurate.

Let us suppose that at *London*, in the year 1761, on the 6th of June, at 55 minutes after V in the morning, the Sun will be in Gemini 15° 37′, and therefore that at its centre the ecliptic is inclined toward the north, in an angle of 6° 10′; and that the visible path of Venus on the Sun's disc at that time declines to the south, making an angle with the ecliptic of 8° 28′: then the path of Venus will also be inclined to the south, with respect to the equator, intersecting the parallels of declination at

an angle of 2° 18'*. Let us also suppose, that Venus, at the forementioned time, will be at her least distance from the Sun's centre, viz. only four minutes to the south; and that every hour she will describe a space of 4 minutes on the Sun, with a retrograde motion. The Sun's semidiameter will be 15' 51'' nearly, and that of Venus 37½''. And let us suppose, for trial's sake, that the difference of the horizontal parallaxes of Venus with the Sun (which we want) is 31'', such as it comes out if the Sun's parallax be supposed 12½''. Then, on the centre *C* (Plate XV Fig. 2.) let the little circle *AB*, representing the Earth's disc, be described, and let his semidiameter *CB* be 31''; and let the ecliptic parallels of 22 and 56 degrees of north latitude (for the *Ganges* and *Port-Nelson*) be drawn within it, in the manner now used by Astronomers for constructing solar eclipses. Let *BCg* be the meridian in which the Sun is, and to this, let the right line *FHG* representing the path of Venus be inclined at an angle of 2° 18'; and let it be distant from the centre *C* 240 such parts, whereof *CB* is 31. From *C* let fall the right line *CH*, perpendicular to *FG*; and suppose Venus to be at *H* at 55 minutes after V in the morning. Let the right line *FHG* be divided into the horary space III IV, IV V, V VI, &c. each equal to *CH*; that is, to 4 minutes of a degree. Also, let the right line *LM* be equal to the diffe-

* This was an oversight in the Doctor, occasioned by his placing both the Earth's axis *BCg* (Fig. 2. of Plate XV.) and the axis of Venus's orbit *CH* on the same side of the axis of the ecliptic *CK*; the former making an angle of 6° 10' therewith, and the latter an angle of 8° 28'; the difference of which angles is only 2° 18'. But the truth is, that the Earth's axis, and the axis of Venus's orbit, will then lie on different sides of the axis of the ecliptic, the former making an angle of 6° therewith, and the latter an angle of 8½°. Therefore, the sum of these angles, which is 14½° (and not their difference 2° 18'), is the inclination of Venus's visible path to the equator and parallels of declination.

rence of the apparent semidiameters of the Sun and Venus, which is 15′ 13½″; and a circle being described with the radius *LM*, on a centre taken in any point within the little circle *AB* representing the Earth's disc, will meet the right line *FG* in a point denoting the time at *London* when Venus shall touch the Sun's limb internally, as seen from the place of the Earth's surface that answers to the point assumed in the Earth's disc. And if a circle be described on the centre *C*, with the radius *LM*, it will meet the right line *FG*, in the points *F* and *G*; and the spaces *FH* and *GH* will be each equal to 14′ 4″, which space Venus will appear to pass over in 3 hours 40 minutes of time at *London*; therefore *F* will fall in II hours 15 minutes, and *G* in IX hours 35 minutes in the morning. Whence it is manifest that if the magnitude of the Earth, on account of its immense distance, should vanish as it were into a point; or if, being deprived of a diurnal motion, it should always have the Sun vertical to the same point *C*; the whole duration of this eclipse would be 7 hours 20 minutes. But the Earth in that time being whirled through 110 degrees of longitude, with a motion contrary to the motion of Venus, and consequently the abovementioned duration being contracted, suppose 12 minutes, it will come out 7 hours 8 minutes, or 107 degrees nearly.

Now Venus will be at *H*, at her least distance from the Sun's centre, when in the meridian of the eastern mouth of the *Ganges*, where the altitude of the pole is about 22 degrees. The Sun therefore will be equally distant from the meridian of that place, at the moments of the ingress and egress of the planet, viz. 53½ degrees; as the points *a* and *b* (representing that place in the Earth's disc *AB*) are, in the greater parallel, from the meridian *BCg*. But the diameter *ef* of that parallel will be to the distance *ab*, as the square of the radius to the rectangle under the sines of 53½ and 68 degrees; that is, of 1′ 2″ to

46″ 13‴. And by a good calculation (which, that I may not tire the reader, it is better to omit) I find that a circle described on *a* as a centre, with the radius *LM*, will meet the right line *FH* in the point *M*, at II hours 20 minutes 40 seconds; but that being described round *b* as a centre, it will meet *HG* in the point *N* at IX hours 29 minutes 22 seconds, according to the time reckoned at *London:* and therefore, Venus will be seen entirely within the Sun at the banks of the *Ganges* for 7 hours 8 minutes 42 seconds: we have then rightly supposed that the duration will be 7 hours 8 minutes, since the part of a minute here is of no consequence.

But adapting the calculation to *Port-Nelson*, I find, that the Sun being about to set, Venus will enter his disc; and immediately after his rising she will leave the same. That place is carried in the intermediate time through the hemisphere opposite to the Sun, from *c* to *d*, with a motion conspiring with the motion of Venus; and therefore, the stay of Venus on the Sun will be about 4 minutes longer, on account of the parallax; so that it will be at least 7 hours 24 minutes, or 111 degrees of the equator. And since the latitude of the place is 56 degrees, as the square of the radius is to the rectangle contained under the sines 55½ and 34 degrees, so is *AB*, which is 1′ 2″, to *cd*, which is 28″ 33‴. And if the calculation be justly made, it will appear that a circle described on *c* as a centre, with the radius *LM*, will meet the right line *FH* in *O* at II hours 12 minutes 45 seconds; and that such a circle described on *d* as a centre, will meet *HG* in *P*, at IX hours 36 minutes 37 seconds; and therefore the duration at *Port-Nelson* will be 7 hours 23 minutes 52 seconds, which is greater than at the mouth of the *Ganges* by 15 minutes 10 seconds of time. But if Venus should pass over the Sun without having any latitude, the difference would be 18 minutes 40 seconds; and

if she should pass 4′ north of the Sun's centre, the difference would amount to 21 minutes 40 seconds, and will be still greater, if the planet's north latitude be more increased.

From the foregoing hypothesis it follows, that at *London*, when the Sun rises, Venus will have entered his disc; and that, at IX hours 37 minutes in the morning, she will touch the limb of the Sun internally at going off; and lastly, that she will not entirely leave the Sun till IX hours 56 minutes.

It likewise follows from the same hypothesis, that the centre of Venus should just touch the Sun's northern limb in the year 1769, on the third of *June*, at XI o'clock at night. So that, on account of the parallax, it will appear in the northern parts of *Norway*, entirely within the Sun, which then does not set to those parts; while, on the coasts of *Peru* and *Chili*, it will seem to travel over a small portion of the disc of the setting Sun; and over that of the rising Sun at the *Molucca Islands*, and in their neighbourhood.—But if the nodes of Venus be found to have a retrograde motion (as there is some reason to believe from some later observations they have), then Venus will be seen every where within the Sun's disc; and will afford a much better method for finding the Sun's parallax, by almost the greatest difference in the duration of these eclipses that can possibly happen.

But how this parallax may be deduced from observations made somewhere in the *East Indies*, in the year 1761, both of the ingress and egress of Venus, and compared with those made in its going off with us, namely, by applying the angles of a triangle given in specie to the circumference of three equal circles, shall be explained on some other occasion.

ARTICLE IV.

Showing that the whole method proposed by the Doctor cannot be put in practice, and why.

27. In the above Dissertation, the Doctor has explained his method with great modesty, and even with some doubtfulness with regard to its full success. For he tells us, that by means of this transit the Sun's parallax may only be determined within its five hundredth part, provided it be not less than $12\frac{1}{2}''$; that there may be a good observation made at *Port-Nelson*, as well as about the banks of the *Ganges;* and that Venus does not pass more than 4 minutes of a degree below the centre of the Sun's disc.—He has taken all proper pains not to raise our expectations too high, and yet, from his well-known abilities, and character as a great astronomer, it seems mankind in general have laid greater stress upon his method, than he ever desired them to do. Only, as he was convinced it was the best method by which this important problem can ever be solved, he recommended it warmly for that reason. He had not then made a sufficient number of observations, by which he could determine, with certainty, whether the nodes of Venus's orbit have any motion; or if they have, whether it be backward or forward with respect to the stars. And consequently, having not then made his own tables, he was obliged to calculate from the best that he could find. But those tables allow of no motion to Venus's nodes, and also reckon her conjunction with the Sun to be about half an hour too late.

28. But more modern observations prove, that the nodes of Venus's orbit have a motion backward, or contrary to the order of the signs, with respect to the fixed stars. And this motion is allowed for in the Doctor's tables, a great part of which were made from his own observations. And

it appears by these tables, that Venus will be so much farther past her descending node at the time of this transit, than she was past her ascending node at her transit, in *November* 1639; that instead of passing only four minutes of a degree below the Sun's centre in this, she will pass almost 10 minutes of a degree below it: on which account, the line of her transit will be so much shortened, as will make her passage over the Sun's disc about an hour and 20 minutes less than if she passed only 4 minutes below the Sun's centre at the middle of her transit. And therefore, her parallax from the Sun will be so much diminished, both at the beginning and end of her transit, and at all places from which the whole of it will be seen, that the difference of its durations, as seen from them, and as supposed to be seen from the Earth's centre, will not amount to 11 minutes of time.

29. But this is not all; for although the transit will begin before the Sun sets to *Port-Nelson*, it will be quite over before he rises to that place next morning, on account of its ending so much sooner than as given by the tables to which the Doctor was obliged to trust. So that we are quite deprived of the advantage that otherwise would have arisen from observations made at *Port-Nelson*.

30. In order to trace this affair through all its intricacies, and to render it as intelligible to the reader as I can, there will be an unavoidable necessity of dwelling much longer upon it than I could otherwise wish. And as it is impossible to lay down truly the parallels of latitude, and the situations of places at particular times, in such a small disc of the Earth as must be projected in such a sort of diagram as the Doctor has given, so as to measure thereby the exact times of the beginning and ending of the transit at any given place, unless the Sun's disc be made at least 30 inches diameter in the projection, and to which the Doctor did not quite trust without making some calculations; I shall take a different

method, in which the Earth's disc may be made as large as the operator pleases: but if he makes it only 6 inches in diameter, he may measure the quantity of Venus's parallax from the Sun upon it, both in longitude and latitude, to the fourth part of a second, for any given time and place; and then, by an easy calculation in the common rule of three, he may find the effect of the parallaxes on the duration of the transit. In this I shall first suppose with the Doctor, that the Sun's horizontal parallax is $12\frac{1}{2}''$; and consequently, that Venus's horizontal parallax from the Sun is $31''$. And after projecting the transit, so as to find the total effect of the parallax upon its duration, I shall next show how nearly the Sun's real parallax may be found from the observed intervals between the times of Venus's egress from the Sun, at particular places of the earth; which is the method now taken both by the *English* and *French* astronomers, and is a surer way whereby to come at the real quantity of the Sun's parallax, than by observing how much the whole contraction of duration of the transit is, either at *Bencoolen*, *Batavia*, or *Pondicherry*.

ARTICLE V.

Showing how to project the transit of Venus on the Sun's disc, as seen from different places of the Earth; so as to find what its visible duration must be at any given place, according to any assumed parallax of the Sun; and from the observed intervals between the times of Venus's egress from the Sun at particular places, to find the Sun's true horizontal parallax.

31. The elements for this projection are as follows:

I. The true time of conjunction of the Sun and Venus; which, as seen from the Earth's centre, and reckoned according to the equal time at

London, is on the 6th of *June* 1761, at 46 minutes 17 seconds after V in the morning, according to Dr. HALLEY's tables.

II. The geocentric latitude of Venus at that time, 9′ 43″ south.

III. The Sun's semidiameter, 15′ 50″.

IV. The semidiameter of Venus (from the Doctor's Dissertation), 37½″.

V. The difference of the semidiameters of the Sun and Venus, 15′ 12½″.

VI. Their sum, 16′ 27½″.

VII. The visible angle which the transit-line makes with the ecliptic 8° 31′; the angular point (or descending node) being 1° 6′ 18″ eastward from the Sun, as seen from the Earth; the descending node being in ♐ 14° 29′ 37″, as seen from the Sun; and the Sun in ♊ 15° 35′ 55″, as seen from the Earth.

VIII. The angle which the axis of Venus's visible path makes with the axis of the ecliptic, 8° 31′; the southern half of that axis being on the left hand (or eastward) of the axis of the ecliptic, as seen from the northern hemisphere of the Earth, which would be to the right hand, as seen from the Sun.

IX. The angle which the Earth's axis makes with the axis of the ecliptic, as seen from the Sun, 6°; the southern half of the Earth's axis lying to the right hand of the axis of the ecliptic, in the projection which would be to the left hand, as seen from the Sun.

X. The angle which the Earth's axis makes with the axis of Venus's visible path, 14° 31′; viz. the Sum of No. VIII. and IX.

XI. The true motion of Venus on the Sun, given by the tables as if it were seen from the Earth's centre, 4 minutes of a degree in 60 minutes of time.

32. These elements being collected, make a scale of any convenient length, as that of Fig. 1. in Plate XVI, and divide it into 17 equal parts, each of which shall be taken for a minute of a degree, then divide the minute next to the left hand into 60 equal parts for seconds, by diagonal lines, as in the figure. The reason for dividing the scale into 17 parts or minutes is, because the sum of the semidiameters of the Sun and Venus exceeds 16 minutes of a degree. See No. VI.

33. Draw the right line *ACG* (Fig. 2.) for a small part of the ecliptic, and perpendicular to it draw the right line *CvE* for the axis of the ecliptic on the southern half of the Sun's disc.

34. Take the Sun's semidiameter, 15′ 50″ from the scale with your compasses; and with that extent, as a radius, set one foot in *C* as a centre, and describe the semicircle *AEG* for the southern half of the Sun's disc; because the transit is on that half of the Sun.

35. Take the geocentric latitude of Venus, 9′ 43″, from the scale with your compasses; and set that extent from *C* to *v*, on the axis of the ecliptic: and the point *v* shall be the place of Venus's centre on the Sun, at the tabular moment of her conjunction with the Sun.

36. Draw the right line *CBD*, making an angle of 8° 31′ with the axis of the ecliptic, toward the left hand; and this line shall represent the axis of Venus's geocentric visible path on the Sun.

37. Through the point of the conjunction *v*, in the axis of the ecliptic, draw the right line *qtr* for the geocentric visible path of Venus over the Sun's disc, at right angles to *CBD*, the axis of her orbit, which axis will divide the line of her path into two equal parts *qt* and *tr*.

38. Take Venus's horary motion on the Sun, 4′ from the scale with your compasses; and with that extent make marks along the transit-line *qtr*. The equal spaces, from mark to mark, show how

much of that line Venus moves through in each hour, as seen from the Earth's centre, during her continuance on the Sun's disc.

39. Divide each of these horary spaces, from mark to mark, into 60 equal parts for minutes of time; and set the hours to the proper marks in such a manner, that the true time of conjunction of the Sun and Venus, 46¾ minutes after V in the morning, may fall into the point *v*, where the transit-line cuts the axis of the ecliptic. So the point *v* shall denote the place of Venus's centre on the Sun, at the instant of her ecliptical conjunction with the Sun, and *t* (in the axis *CtD* of her orbit) will be the middle of her transit; which is at 24 minutes after V in the morning, as seen from the Earth's centre, and reckoned by the equal time at *London*.

40. Take the difference of the semidiameters of the Sun and Venus, 15′ 12½″, in your compasses from the scale; and with that extent, setting one foot in the Sun's centre *C*, describe the arcs *N* and *T* with the other crossing the transit-line in the points *k* and *l*; which are the points on the Sun's disc that are hid by the centre of Venus at the moments of her two internal contacts with the Sun's limb or edge, at *M* and *N*: the former of these is the moment of Venus's total ingress on the Sun, as seen from the Earth's centre, which is at 28 minutes after II in the morning, as reckoned at *London*; and the latter is the moment when her egress from the Sun begins, as seen from the Earth's centre, which is 20 minutes after VIII in the morning at *London*. The interval between these two contacts is 5 hours 52 minutes.

41. The central ingress of Venus on the Sun is the moment when her centre is on the Sun's eastern limb at *u*, which is at 15 minutes after two in the morning: and her central egress from the Sun is the moment when her centre is on the Sun's western limb at *w*; which is at 33 minutes after VIII in

the morning, as seen from the Earth's centre, and reckoned according to the time at *London*. The interval between these times is 6 hours 18 minutes.

42. Take the sum of the semidiameters of the Sun and Venus, 16′ 27½″, in your compasses from the scale; and with that extent, setting one foot in the Sun's centre *C*, describe the arcs *Q* and *R* with the other, cutting the transit-line in the points *q* and *r*, which are the points in open space (clear of the Sun) where the centre of Venus is, at the moments of her two external contacts with the Sun's limb at *S* and *W*; or the moments of the beginning and ending of the transit as seen from the Earth's centre; the former of which is at 3 minutes after II in the morning at *London*, and the latter at 45 minutes after VIII. The interval between these moments is 6 hours 42 minutes.

43. Take the semidiameter of Venus 37½″, in your compasses from the scale: and with that extent as a radius, on the points *q*, *k*, *t*, *l*, *r*, as centres, describe the circles *HS*, *MI*, *OF*, *PN*, *WY*, for the disc of Venus, at her first contact at *S*, her total ingress at *M*, her place on the Sun at the middle of her transit, her beginning of egress at *N*, and her last contact at *W*.

44. Those who have a mind to project the Earth's disc on the Sun, round the centre *C*, and to lay down the parallels of latitude and situations of places thereon, according to Dr. Halley's method, may draw *Cf* for the axis of the Earth, produced to the southern edge of the Sun at *f*; and making an angle *ECf* of 6° with the axis of the ecliptic *CE*: but he will find it very difficult and uncertain to mark the places on that disc, unless he makes the Sun's semidiameter *AC* 15 inches at least: otherwise the line *Cf* is of no use at all in this projection.—The following method is better.

45. In Fig. 3. of Plate XVI make the line *AB* of any convenient length, and divide it into 31 equal parts, each of which may be taken for a second

of Venus's parallax either from or upon the Sun (her horizontal parallax from the Sun being supposed to be 31″); and taking the whole length *AB* in your compasses, set one foot in *C* (Fig. 4.) as a centre, and describe the circle *AEBD* for the Earth's enlightened disc, whose diameter is 62″, or double the horizontal parallax of Venus from the Sun. In this disc, draw *ACB* for a small part of the ecliptic, and at right angles to it draw *ECD* for the axis of the ecliptic. Draw also *NCS* both for the Earth's axis and universal solar meridian, making an angle of 6° with the axis of the ecliptic, as seen from the Sun; *HCI* for the axis of Venus's orbit, making an angle of 8° 31′ with *ECD*, the axis of the ecliptic; and lastly, *FCO* for a small part of Venus's orbit, at right angles to its axis.

46. This figure represents the Earth's enlightened disc, as seen from the Sun at the time of the transit. The parallels of latitude of *London*, the eastern mouth of the *Ganges*, *Bencoolen*, and the island of *St. Helena*, are laid down in it, in the same manner as they would appear to an observer on the Sun, if they were really drawn in circles on the Earth's surface (like those on a common terrestrial globe) and could be visible at such a distance.—The method of delineating these parallels is the same as already described in the XIXth chapter, for the construction of solar eclipses.

47. The points where the curve-lines (called hour-circles) XI *N*, X *N*, &c. cut the parallels of latitude, or paths of the four places above mentioned, are the points at which the places themselves would appear in the disc, as seen from the Sun, at these hours respectively. When either place comes to the solar meridian *NCS* by the Earth's rotation on its axis, it is noon at that place; and the difference, in absolute time, between the noon at that place and the noon at any other place, is in proportion to the difference of longitude of these two places, reckoning one hour for every 15 degrees of

longitude, and 4 minutes for each degree: adding the time if the longitude be east, but subtracting it if the longitude be west.

48. The distance of either of these places from *HCI* (the axis of Venus's* orbit) at any hour or part of an hour, being measured upon the scale *AB* in Fig. 3. will be equal to the parallax of Venus from the Sun in the direction of her path; and this parallax, being always contrary to the position of the place, is eastward as long as the place keeps on the left hand of the axis of the orbit of Venus, as seen from the sun; and westward when the place gets to the right hand of that axis. So that, to all the places which are posited in the hemisphere *HVI* of the disc, at any given time, Venus has an eastern parallax; but when the Earth's diurnal motion carries the same places into the hemisphere *HOI*, the parallax of Venus is westward.

49. When Venus has a parallax toward the east, as seen from any given place on the Earth's surface, either at the time of her total ingress, or beginning of egress, as seen from the Earth's centre; add the time answering to this parallax to the time of ingress or egress at the Earth's centre, and the sum will be the time, as seen from the given place on the Earth's surface: but when the parallax is westward, subtract the time answering to this parallax from the time of total ingress or beginning of egress, as seen from the Earth's centre, and the remainder will be the time, as seen from the given place on the surface, so far as it is affected by this parallax.—The reason of this is plain to every one who considers,

* In a former edition of this, I made a mistake, in taking the parallax in longitude instead of the parallax in the direction of the orbit of Venus, and the parallax in latitude instead of the parallax in lines perpendicular to her orbit. But in this edition, these errors are corrected; which make some small differences in the quantities of the parallaxes, and in the times depending on them, as will appear by comparing them in this with those in the former edition.

that an eastern parallax keeps the planet back, and a western parallax carries it forward, with respect to its true place or position, at any instant of time, as seen from the Earth's centre.

50. The nearest distance of any given place from *VCO*, the plane of Venus's orbit at any hour or part of an hour, being measured on the scale *AB* in Fig. 3. will be equal to Venus's parallax in lines perpendicular to her path; which is northward from the true line of her path on the Sun, as seen from the Earth's centre, if the given place be on the south side of the plane of her orbit *VCO* on the Earth's disc; and the contrary, if the given place be on the north side of that plane; that is, the parallax is always contrary to the situation of the place on the Earth's disc, with respect to the plane of Venus's orbit on it.

51. As the line of Venus's transit is on the southern hemisphere of the Sun's disc, it is plain that a northern parallax will cause her to describe a longer line on the Sun, than she would if she had no such parallax; and a southern parallax will cause her to describe a shorter line on the Sun, than if she had no such parallax.—And the longer this line is, the sooner will her total ingress be, and the later will be her beginning of egress; and just the contrary, if the line be shorter.—But to all places situate on the north side of the plane of her orbit, in the hemisphere *VHO*, the parallax in lines perpendicular to her orbit is south; and to all places situate on the south side of the plane of her orbit, in the hemisphere *VIO*, this parallax is north. Therefore, the line of the transit will be shorter to all places in the hemisphere *VHO*, than it will be, as seen from the Earth's centre, where there is no parallax; and longer to all places in the hemisphere *VIO*. So that the time answering to this parallax must be added to the time of total ingress, as seen from the Earth's centre, and subtracted from the beginning of egress, as

seen from the Earth's centre, in order to have the true time of total ingress and beginning of egress as seen from places in the hemisphere *VHO:* and just the reverse for places in the hemisphere *VIO.*—It was proper to mention these circumstances, for the reader's more easily conceiving the reason of applying the times answering to these parallaxes in the subsequent part of this article: for it is their sum in some cases, and their difference in others, which being applied to the times of total ingress and beginning of egress as seen from the Earth's centre, that will give the times of these phenomena as seen from given places on the Earth's surface.

52. The angle which the Sun's semidiameter subtends, as seen from the Earth, at all times of the year, has been so well ascertained by late observations, that we can make no doubt of its being 15′ 50″ on the day of the transit; and Venus's latitude has also been so well ascertained at many different times of late, that we have very good reason to believe it will be 9′ 43″ south of the Sun's centre at the time of her conjunction with the Sun.—If then her semidiameter at that time be 37½″ (as mentioned by Dr. Halley) it appears by the projection (Fig. 2.) that her total ingress on the Sun, as seen from the Earth's centre, will be at 28 minutes after two in the morning (§40.), and her beginning of egress from the Sun will be 20 minutes after VIII, according to the time reckoned at *London.*

53. As the total ingress will not be visible at *London* we shall not here trouble the reader about Venus's parallax at that time.—But by projecting the situation of *London* on the Earth's disc (Fig. 4.) for the time when the egress begins, we find it will then be at *l*, as seen from the Sun.

Draw *ld* parallel to Venus's orbit *VCO*, and *lu* perpendicular to it: the former is Venus's eastern parallax in the direction of her path at the beginning of her egress from the Sun, and the latter is her

southern parallax in a direction at right angles to her path at the same time. Take these in your compasses, and measure them on the scale *AB* (Fig. 3.) and you will find the former parallax to be 10¾″, and the latter 21⅓″.

54. As Venus's true motion on the Sun is at the rate of four minutes of a degree in 60 minutes of time (*See* No. XI. *of* § 31.) say, as 4 minutes of a degree is to 60 minutes of time, so is 10¾″ of a degree to 2 minutes 41 seconds of time; which being added to VIII hours 20 minutes (because this parallax is eastward, § 49.) gives VIII hours 22 minutes 41 seconds, for the beginning of egress at *London* as affected only by this parallax.—But as Venus has a southern parallax at that time, her beginning of egress will be sooner; for this parallax shortens the line of her visible transit at *London*.

55. Take the distance *Ct* (Fig. 2.), or nearest approach of the centres of the Sun and Venus in your compasses, and measure it on the scale (Fig. 1.), and it will be found to be 9′ 36½″; and as the parallax of Venus from the Sun in a direction which is at right angles to her path is 21⅓″ south, add it to 9′ 36½″, and the sum will be 9′ 58″; which is to be taken from the scale in Fig. 1. and set from *C* to *L* in Fig. 2. And then, if a line be drawn parallel to *tl*, it will terminate at the point *p* in the arc *T*, where Venus's centre will be at the beginning of her egress, as seen from *London**.—But as her centre is at *l* when her egress begins as seen from the Earth's centre, take *Lp* in your compasses, and setting that extent from *t* toward *l* on the central transit-line, you will find it to be 5 minutes shorter than *tl*: therefore subtract 5 minutes from VIII hours 22 minutes 41 seconds, and there will remain VIII

* The reason why the lines *oLp*, *aBb*, *ct*, and *th*, which are the visible transits at *London*, the *Ganges* mouth, *Bencoolen*, and *St Helena*, are not parallel to the central transit line *tl*, is because the parallaxes in latitude are different at the times of ingress and egress, as seen from each of these places. The method of drawing these lines will be shown by-and-by

hours 17 minutes 41 seconds for the visible beginning of egress in the morning at *London*.

56. At V hours 24 minutes (which is the middle of the transit, as seen from the Earth's centre) *London* will be at *L* on the Earth's disc (Fig. 4.) as seen from the Sun. The parallax *La* of Venus from the Sun in the direction of her path is then 12½″; by which, working as above directed, we find the middle of the transit, as seen from *London*, will be at V hours 20 minutes 53 seconds.—This is not affected by *Lt* the parallax at right angles to the path of Venus.—But *Lt* measures 27″ on the scale *AB* (Fig. 3.): therefore take 27″ from the scale in Fig. 1. and set it from *t* to *L*, on the axis of Venus's path in Fig. 2. and laying a ruler to the point *L*, and the above-found point of egress *p*, draw *oLp* for the line of the transit as seen from *London*.

57. The eastern mouth of the river *Ganges* is 89 degrees east from the meridian of *London*; and therefore, when the time at *London* is 28 minutes after II in the morning (§ 40.) it is 24 minutes past VIII in the morning (by § 47.) at the mouth of the *Ganges*; and when it is twenty minutes past VIII in the morning at *London* (§ 40.) it is 16 minutes past II in the afternoon at the *Ganges*. Therefore, by projecting that place upon the Earth's disc, as seen from the Sun, it will be at *G* (in Fig. 4.), at the time of Venus's total ingress, as seen from the Earth's centre, and at *g* when her egress begins.

Draw *Ge* and *gr* parallel to the orbit of Venus *VCO*, and measure them on the scale *AB* in Fig. 3. the former will be 21″ for Venus's eastern parallax in the direction of her path, at the above-mentioned time of her total ingress, and the latter will be 16¾″ for her western parallax at the time when her egress begins.—The former parallax gives 5 minutes 15 seconds of time (by the analogy in § 54.) to be added to VIII hours 24 minutes, and the latter parallax gives 4 minutes 11 seconds to be subtracted from II hours 16 minutes; by which we have VIII

hours 29 minutes 15 seconds, for the time of total ingress, as seen from the banks of the *Ganges*, and II hours 11 minutes 49 seconds from the beginning of egress, as affected by these parallaxes.

Draw *Gf* perpendicular to Venus's orbit *VOC*, and by measurement on the scale *AB* (Fig. 3.) it will be found to contain 10″: take 10″ from the scale in Fig. 1. and find, by trials, a point *c*, in the arch *N*, where, if one foot of the compasses be placed, the other will just touch the central transit-line *kl*. Take the nearest distance from this point *c* to *CL*, the axis of Venus's orbit, and applying it from *t* toward *k*, you will find it fall a minute short of *k*; which shows, that Venus's parallax in this direction shortens the beginning of the line of her visible transit at the *Ganges* by one minute of time. Therefore, as this makes the visible ingress a minute later, add one minute to the above VIII hours 29 minutes 15 seconds, and it will give VIII hours 30 minutes 15 seconds for the time of total ingress in the morning, as seen from the eastern mouth of the *Ganges*. At the beginning of egress, the parallax *gp* in the same direction is 21½″ (by measurement on the scale *AB*), which will protract the beginning of egress by about 30 seconds of time, and must therefore be added to the above II hours 11 minutes 49 seconds, which will make the visible beginning of egress to be at II hours 12 minutes 19 seconds in the afternoon.

58. *Bencoolen* is 102 degrees east from the meridian of *London*; and therefore, when the time is 28 minutes past II in the morning at *London*, it is 16 minutes past IX in the morning at *Bencoolen*; and when it is 20 minutes past VIII in the morning at *London*, it is 8 minutes past III in the afternoon at *Bencoolen*. Therefore, in Fig. 4. *Bencoolen* will be at *B* at the time of Venus's total ingress, as seen from the Earth's centre; and at *b* when her egress begins

Draw *Bi* and *bk* parallel to Venus's orbit *VCO*, and measure them on the scale: the former will be found to be 22″ for Venus's eastern parallax in the direction of her path at the time of her total ingress; and the latter to be 19½″ for her western parallax in the same direction when her egress begins, as seen from the Earth's centre. The first of these parallaxes gives 5 minutes 30 seconds (by the analogy in § 54.) to be added to IX hours 16 minutes, and the latter parallax gives 4 minutes 52 seconds to be subtracted from III hours 8 minutes; whence we have IX hours 21 minutes 30 seconds for the time of total ingress at *Bencoolen:* and III hours 3 minutes and 8 seconds for the time when the egress begins there, as affected by these two parallaxes.

59. Draw *bv* and *bm* perpendicular to Venus's orbit *VCO*, and measure them on the scale *AB:* the former will be 5″ for Venus's northern parallax in a direction perpendicular to her path, as seen from *Bencoolen*, at the time of her total ingress; and the latter will be 15½″ for her northern parallax in that direction when her egress begins. Take these parallaxes from the scale, Fig. 1. in your compasses, and find by trials, two points in the arcs *N* and *T* (Fig. 2.) where if one foot of the compasses be placed, the other will touch the central transit-line *kl:* draw a line from *a* to *b*, for the line of Venus's transit as seen from *Bencoolen;* the centre of Venus being at *a*, as seen from *Bencoolen*, at the moment of her total ingress; and at *b* at the moment when her egress begins.

But as seen from the Earth's centre, the centre of Venus is at *k* in the former case, and at *l* in the latter: so that we find the line of the transit is longer as seen from *Bencoolen* than as seen from the Earth's centre, which is the effect of Venus's northern parallax.—Take *Ba* in your compasses, and setting that extent backward from *t* toward *g*, on the central transit-line, you will find it will reach two minutes beyond *k:* and taking the extent *Bb*

in your compasses, and setting it forward from *t* toward *w*, on the central transit-line, it will be found to reach 3 minutes beyond *l*. Consequently, if we subtract 2 minutes from IX hours 21 minutes 30 seconds (above found), we have IX hours 19 minutes 30 seconds in the morning, for the time of total ingress, as seen from *Bencoolen:* and if we add 3 minutes to the above-found III hours 3 minutes 8 seconds, we shall have III hours 6 minutes 8 seconds afternoon, for the time when the egress begins, as seen from *Bencoolen*.

60. The whole duration of the transit, from the total ingress to the beginning of egress, as seen from the Earth's centre, is 5 hours 52 minutes (by § 40.); but the whole duration from the total ingress to the beginning of egress, as seen from *Bencoolen*, is only 5 hours 46 minutes 38 seconds: which is 5 minutes 22 seconds less than as seen from the Earth's centre: and this 5 minutes 22 seconds is the whole effect of the parallaxes (both in longitude and latitude) on the duration of the transit at *Bencoolen*.

But the duration, as seen at the mouth of the *Ganges*, from ingress to egress, is still less; for it is only 5 hours 42 minutes 4 seconds; which is 9 minutes 56 seconds less than as seen from the Earth's centre, and 4 minutes 34 seconds less than as seen at *Bencoolen*.

61. The island of *St. Helena* (to which only a small part of the transit is visible at the end) will be at *H* (as in Fig. 4.) when the egress begins as seen from the Earth's centre. And since the middle of that island is 6° west from the meridian of *London*, and the said egress begins when the time at *London* is 20 minutes past VIII in the morning, it will then be only 56 minutes past VII in the morning at *St. Helena*.

Draw *Hn* parallel to Venus's orbit *VCO*, and *Ho* perpendicular to it; and by measuring them on the scale *AB* (Fig. 3.) the former will be found to amount to 29″ for Venus's eastern parallax in the

direction of her path, as seen from *St. Helena*, when her egress begins, as seen from the Earth's centre; and the latter to be 6″ for her northern parallax in a direction at right angles to her path.

By the analogy in § 54, the parallax in the direction of the path of Venus gives 10 minutes 2 seconds of time; which being added (on account of its being eastward) to VII hours 56 minutes, gives VIII hours 6 minutes 2 seconds for the beginning of egress at *St. Helena*, as affected by this parallax. —But 6″ of parallax in a perpendicular direction to her path (applied as in the case of *Bencoolen*) lengthens out the end of the transit-line by one minute; which being added to VIII hours 6 minutes 2 seconds, gives VIII hours 7 minutes 2 seconds for the beginning of egress, as seen from *St. Helena*.

62. We shall now collect the above-mentioned times into a small table, that they may be seen at once, as follows: *M* signifies morning, *A* afternoon.

		Total ingress. H. M. S.	Beg. of egress. H. M. S.	Duration. H. M. S.
	The Earth's centre	II 28 0 *M*	VIII 20 0 *M*	5 52 0*
	London - - -	Invisible *M*	VIII 17 41 *M*	— — —
♀	The *Ganges* mouth	VIII 30 15 *M*	II 12 19 *A*	5 42 4
	Bencoolen - -	IX 19 30 *M*	III 6 8 *A*	5 46 38
	St. Helena - -	Invisible *M*	VIII 7 2 *M*	— — —

63. The times at the three last-mentioned places are reduced to the meridian of *London*, by subtracting 5 hours 56 minutes from the times of ingress and egress at the *Ganges*; 6 hours 48 minutes from the times at *Bencoolen*; and adding 24

* This duration as seen from the Earth's centre, is on supposition that the semidiameter of Venus would be found equal to $37\frac{1}{2}''$, on the Sun's disc, as stated by Dr. *Halley* (see Art. V. § 51.), to which all the other durations are accommodated.—But, from later observations, it is highly probable, that the semidiameter of Venus will be found not to exceed 30″ on the Sun, and if so, the duration between the two internal contacts, as seen from the Earth's centre, will be 5 hours 58 minutes, and the duration as seen from the above-mentioned places, will be lengthened very nearly in the same proportion.

minutes to the time of beginning of egress at *St. Helena:* and being thus reduced, they are as follows:

		Total Ingress. H. M. S.	Beg. of egress. H. M. S.	
Times at *London* for	*Ganges* mouth	II 34 15*M*	VIII 16 19*M*	Durations as above.
	Bencoolen - -	II 31 30*M*	VIII 18 8*M*	
	St. Helena - -	Invisible *M*	VIII 31 2*M*	

64 All this is on supposition, that we have the true longitudes of the three last-mentioned places, that the Sun's horizontal parallax is 12¼″ that the true latitude of Venus is given, and that her semidiameter will subtend an angle of 37½″ on the Sun's disc.

As for the longitudes, we must suppose them true, until the observers ascertain them, which is a very important part of their business; and without which they can by no means find the interval of absolute time that elapses between either the ingress or egress, as seen from any two given places: and there is much greater dependence to be had on this elapse, than upon the whole contraction of duration at any given place, as it will undoubtedly afford a surer basis for determining the Sun's parallax.

65. I have good reason to believe that the latitude of Venus, as given in § 31, will be found by observation to be very near the truth; but that the time of conjunction there mentioned will be found later than the true time by almost 5 minutes; that Venus's semidiameter will subtend an angle of no more than 30″ on the Sun's disc; and that the middle of her transit as seen from the Earth's centre, will be at 24 minutes after V in the morning, as reckoned by the equal time at *London*.

66. Subtract VIII hours 17 minutes 41 seconds, the time when the egress begins at *London*, from VIII hours 31 minutes 2 seconds, the time reckoned at *London* when the egress begins at *St. Helena*, and

there will remain 13 minutes 21 seconds (or 801 seconds) for their difference or elapse, in absolute time, between the beginning of egress, as seen from these two places.

Divide 801 seconds by the Sun's parallax $12\frac{1}{2}''$, and the quotient will be 64 seconds and a small fraction. So that for each second of a degree in the Sun's horizontal parallax (supposing it to be $12\frac{1}{2}''$) there will be a difference or elapse of 64 seconds of absolute time between the beginning of egress as seen from *London*, and as seen from *St. Helena;* and consequently 32 seconds of time for every half second of the Sun's parallax; 16 seconds of time for every fourth part of a second of the Sun's parallax; 8 seconds of time for the eighth part of a second of the Sun's parallax; and full 4 seconds for a sixteenth part of the Sun's parallax. For in so small an angle as that of the Sun's parallax, the arc is not sensibly different from either its sine or its tangent: and therefore the quantity of this parallax is in direct proportion to the absolute difference in the time of egress arising from it at different parts of the Earth.

67. Therefore, when this difference is ascertained by good observations, made at different places, and compared together, the true quantity of the Sun's parallax will be very nearly determined. For, since it may be presumed that the beginning of egress can be observed within 2 seconds of its real time, the Sun's parallax may then be found within the 32d part of a second of its true quantity; and consequently, his distance may be found within a 400th part of the whole, provided his parallax be not less than $12\frac{1}{2}''$; for 32 times $12\frac{1}{2}$ is 400.

68. But since Dr. HALLEY has assured us, that he had observed the two internal contacts of the planet Mercury with the Sun's edge so exactly as not to err one second in the time, we may well imagine that the internal contacts of Venus with the Sun may be observed with as great accuracy. So

that we may hope to have the absolute interval between the moments of her beginning of egress, as seen from *London*, and from *St. Helena*, true to a second of time; and if so, the Sun's parallax may be determined to the 64th part of a second, provided it be not less than 12½″: and consequently his distance may be found, within its 800th part; for 64 times 12½ is 800: which is still nearer the truth than Dr. HALLEY expected it might be found by observing the whole duration of the transit in the *East-Indies* and at *Port-Nelson*. So that our present astronomers have judiciously resolved to improve the Doctor's method, by taking only the interval between the absolute times of its ending at different places. If the Sun's parallax be greater or less than 12½″, the elapse or difference of absolute time between the beginning of egress at *London* and at *St. Helena*, will be found by observation to be greater or less than 801 seconds accordingly.

69. There will also be a great difference between the absolute times of egress at *St. Helena* and the northern parts of *Russia*, which would make these places very proper for observation. The difference between them at *Tobolsk* in *Siberia*, and at *St. Helena*, will be 11 minutes, according to DE L'ISLE's map: at *Archangel* it will be but about 40 seconds less than at *Tobolsk;* and only a minute and a quarter less at *Petersburgh*, even if the Sun's parallax be no more than 10½″. At *Wardhus* the same advantage would nearly be gained as at *Tobolsk;* but if the observers could go still farther to the east, as to *Yakoutsk* in *Siberia*, the advantage would be still greater: for, as M. DE L'ISLE very justly observes, in a memoir presented to the *French* king with his map of the transit, the difference of time between Venus's egress from the Sun at *Yakoutsk* and at the *Cape of Good Hope* will be 13¼ minutes.

70. This method requires that the longitude of each place of observation be ascertained to the

greatest degree of nicety, and that each observer's clock be exactly regulated to the equal time at his place: for without these particulars it would be impossible for the observers to reduce the times to those which are reckoned under any given meridian; and without reducing the observed times of egress at different places to the time at some given place, the absolute time that elapses between the egress at one place and at another could not be found. But the longitudes may be found by observing the eclipses of Jupiter's satellites; and a true meridian, for regulating the clock, to the time at any place, may be had by observing when any given star within 20 or 30 degrees of the pole, is stationary with regard to its azimuth on the east and west sides of the pole; the pole itself being the middle point between these two stationary positions of the star. And it is not material for the observers to know exactly either the true angular measure of the Sun's diameter, or of Venus's, in this case; for whatever their diameters be, it will make no sensible difference in the observed interval between the same contact, as seen from different places.

71. In the geometrical construction of transits, the scale *AB* (Fig. 3. of Plate XVI) may be divided into any given number of equal parts, answering to any assumed quantity of Venus's horizontal parallax from the Sun (which is always the difference between the horizontal parallax of Venus and that of the Sun), provided the whole length of the scale be equal to the semidiameter of the Earth's disc in Fig. 4.—Thus if we suppose Venus's horizontal parallax from the Sun to be only 26″ (instead of 31″) in which case the Sun's horizontal parallax must be 10″.3493, as in § 20, the rest of the projection will answer to that scale: as *CD*, which contains only 26 equal parts, is the same length as *AB*, which contains 31. And by working in all other respects as taught from § 45 to

§ 62, you will find the times of total ingress and beginning of egress; and consequently the duration of the transit at any given place, which must result from such a parallax.

72. In projections of this kind, it may be easily conceived, that a right line passing continually through the centre of Venus, and a given point of the Earth, and produced to the Sun's disc, will mark the path of Venus on the Sun, as seen from the given point of the Earth: and in this there are three cases. 1. When the given point is the Earth's centre, at which there is no parallax, either in longitude or latitude. 2. When the given point is one of the poles, where there is no parallax of longitude; but a parallax of latitude, whose quantity is easily determined, by letting fall a perpendicular from the pole upon the plane of the ecliptic, and setting off the parallax of latitude on this perpendicular: and here the polar transit-lines will be parallel to the central, as the poles have no motion arising from the Earth's diurnal rotation. 3. The last case is, when the given point of the Earth is any point of its surface, whose latitude is less than 90 degrees: then there is a parallax in latitude proportional to the perpendicular let fall upon the abovesaid plane, from the given point; and a parallax in longitude proportional to the perpendicular let fall upon the axis of that plane, from the said given point. And the effect of this last will be to alter the transit-line, both in position and length; and will prevent its being parallel to the central transit-line, unless when its axis and the axis of the Earth coincide, as seen from the Sun; which is a thing that may not happen in many ages.

ARTICLE VI.

Concerning the map of the transit. Plate XVII.

73. The title of this map, and the lines drawn upon it, together with the words annexed to these lines, and the numbers (hours and minutes) on the dotted lines, explain the whole of it so well, that no farther description seems requisite.

74. So far as I can examine the map by a good globe, the black curve-lines are in general pretty well laid down, for shewing at what places the transit will begin, or end, at sun-rising or sun-setting, to all those places through which they are drawn, according to the times mentioned in the map. Only I question much whether the transit will begin at sun-rise to any place in *Africa*, that is west of the *Red-Sea;* and am pretty certain that the Sun will not be risen to the northernmost part of *Madagascar* when the transit begins, as M. DE L'ISLE reckons the first contact of Venus with the Sun to be the beginning of the transit. So that the line which shews the entrance of Venus on the Sun's disc at sun-rising, seems to be a little too far west in the map, at all places which are south of *Asia Minor:* but in *Europe*, I think it is very well.

75. In delineating this map, I had M. DE L'ISLE's map of the transit before me. And the only difference between his map and this, is, 1. That in his map, the times are computed to the meridian of *Paris;* in this they are reduced to the meridian of *London*. 2. I have changed his meridional projection into that of the equatorial; by which, I apprehend that the black curve-lines, shewing at what places the transit begins, or ends, with the rising or setting Sun, appear more natural to the eye, and are more fully seen at once, than in the map from which I copied; for in that map the lines are interrupted and broken in the meridian

that divides the hemispheres; and the places where they should join cannot be perceived so readily by those who are not well skilled in the nature of stereographical projections.—The like may be said of many of the dotted curve-lines, on which are expressed the hours and minutes of the beginning or ending of the transit, which are the absolute times at these places through which the lines are drawn, computed to the meridian of *London*.

ARTICLE VII.

Containing an account of Mr. HORROX's *observation of the transit of Venus over the Sun, in the year* 1639; *as it is published in the* Annual Register *for the year* 1761.

76. When *Kepler* first constructed his (the Rudolphine) tables upon the observations of *Tycho*, he soon became sensible that the planets Mercury and Venus would sometimes pass over the Sun's disc; and he predicted two transits of Venus, one for the year 1631, and the other for 1761, in a tract published at *Leipsick* in 1629, intitled, *Admonitio ad Astronomos, &c.* *Kepler* died some days before the transit in 1631, which he had predicted was to happen. *Gassendi* looked for it at *Paris*, but in vain (see *Mercurius in Sole visus, & Venus invisa*). In fact, the imperfect state of the Rudolphine tables was the cause that the transit was expected in 1631, when none could be observed; and those very tables did not give reason to expect one in 1639, when one was really observed.

When our illustrious countryman Mr. HORROX first applied himself to astronomy, he computed ephemerides for several years, from *Lansbergius*'s tables. After continuing his labours for some time, he was enabled to discover the imperfection of these tables; upon which he laid aside his work, intending

to determine the positions of the stars from his own observations. But that the former part of his time spent in calculating from *Lansbergius* might not be thrown away, he made use of his ephemerides to point out to him the situations of the planets. Hence he foresaw when their conjunctions, their appulses to the fixed stars, and the most remarkable phenomena in the heavens would happen; and prepared himself with the greatest care to observe them.

Hence he was encouraged to wait for the important observation of the transit of Venus in the year 1639; and no longer thought the former part of his time mispent, since his attention to *Lansbergius*'s tables had enabled him to discover that the transit would certainly happen on the 24th of *November*. However, as these tables had so often deceived him, he was unwilling to rely on them entirely, but consulted other tables, and particularly those of *Kepler*: accordingly in a letter to his friend *William Crabtree*, of *Manchester*, dated *Hool*, *October* 26, 1639, he communicated his discovery to him, and earnestly desired him to make whatever observations he possibly could with his telescope, particularly to measure the diameter of the planet Venus; which, according to *Kepler*, would amount to 7 minutes of a degree, and according to *Lansbergius* to 11 minutes; but which, according to his own proportion, he expected would hardly exceed one minute. He adds, that according to *Kepler*, the conjunction will be *November* 24, 1639, at 8 hours 1 minute A. M. at *Manchester*, and that the planet's latitude would be 14′ 10″ south; but according to his own corrections he expected it to happen at 3 hours 57 min. P. M. at *Manchester*, with 10′ south latitude. But because a small alteration in *Kepler's* numbers would greatly alter the time of conjunction, and the quantity of the planet's latitude, he advises to watch the whole day, and even on the preceding afternoon, and the morning of the 25th, though he was entirely of opinion that the transit would happen on the 24th.

After having fully weighed and examined the several methods of observing this uncommon phenomenon, he determined to transmit the Sun's image through a telescope into a dark chamber, rather than through a naked aperture, a method greatly commended by *Kepler;* for the Sun's image is not given sufficiently large and distinct by the latter, unless at a very great distance from the aperture, which the narrowness of his situation would not allow of; nor would Venus's diameter be well defined, unless the aperture were very small; whereas his telescope, which rendered the solar spots distinctly visible, would shew him Venus's diameter well defined, and enable him to divide the Sun's limb more accurately.

He described a circle on paper which nearly equalled six inches, the narrowness of the place not allowing a larger size; but even this size admitted divisions sufficiently accurate. He divided the circumference into 360 degrees, and the diameter into 30 equal parts, each of which was subdivided into 4, and the whole therefore into 120. The subdivision might have still been carried farther, but he trusted rather to the accuracy and niceness of his eye.

When the time of observation drew near, he adjusted the apparatus, and caused the Sun's distinct image exactly to fill the circle on the paper: and though he could not expect the planet to enter upon the Sun's disc before three o'clock in the afternoon of the 24th, from his own corrected numbers, upon which he chiefly relied; yet, because the calculations in general from other tables gave the time of conjunction much sooner, and some even on the 23d, he observed the Sun from the time of its rising till nine o'clock; and again, a little before ten, at noon, and at one in the afternoon; being called in the intervals to business of the highest moment, which he could not neglect. But in all these times

he saw nothing on the Sun's face, except one small spot, which he had seen on the preceding day; and which also he afterward saw on some of the following days.

But at 3 hours 15 minutes in the afternoon, which was the first opportunity he had of repeating his observations, the clouds were entirely dispersed, and invited him to seize this favourable occasion, which seemed to be providentially thrown in his way; for he then beheld the most agreeable sight, a spot, which had been the object of his most sanguine wishes, of an unusual size, and of a perfectly circular shape, just wholly entered upon the Sun's disc on the left side: so that the limbs of the Sun and Venus perfectly coincided in every point of contact. He was immediately sensible that this spot was the planet Venus, and applied himself with the utmost care to prosecute his observations.

And, *First*, with regard to the inclination, he found, by means of a diameter of the circle set perpendicular to the horizon, the plane of the circle being somewhat reclined on account of the Sun's altitude, that Venus had wholly entered upon the Sun's disc, at 3 hours 15 minutes, at about 62° 30′ (certainly between 60° and 65°) from the vertex toward the right hand. (These were the appearances within the dark chamber, where the Sun's image and motion of the planet on it were both inverted and reversed.) And this inclination continued constant, at least to all sense, till he had finished the whole of his observation.

Secondly, The distances observed afterward between the centres of the Sun and Venus were as follows: At 3 hours 15 minutes by the clock, the distance was 14′ 24″; at 3 hours 35 minutes, the distance was 13′ 30″; at 3 hours 45 minutes, the distance was 13′ 0″. The apparent time of sun-setting was at 3 hours 50 minutes—the true time 3 hours

15 minutes,—refraction keeping the Sun above the horizon for the space of 5 minutes.

Thirdly, He found Venus's diameter, by repeated observations, to exceed a thirtieth part of the Sun's diameter, by a sixth, or at most a fifth subdivision. —The diameter therefore of the Sun to that of Venus may be expressed, as 30 to 1.12. It certainly did not amount to 1.30, nor yet to 1.20. And this was found by observing Venus as well when near the Sun's limb, as when farther removed from it.

The place where this observation was made, was an obscure village called *Hool*, about 15 miles northward of *Liverpool*. The latitude of *Liverpool* had been often determined by *Horrox* to be 53° 20′; and therefore, that of *Hool* will be 53° 35′. The longitude of both seemed to him to be about 22° 30′ from the *Fortunate Islands*: that is, 14° 15′ to the west of *Uraniburg*.

These were all the observations which the shortness of the time allowed him to make upon this most remarkable and uncommon sight; all that could be done, however, in so small a space of time, he very happily executed; and scarce any thing farther remained for him to desire. In regard to the inclination alone, he could not obtain the utmost exactness; for it was extremely difficult, from the Sun's rapid motion, to observe it to any certainty within the degree. And he ingenuously confesses that he neither did, nor could possibly perform it. The rest are very much to be depended upon; and as exact as he could wish.

Mr. *Crabtree*, at *Manchester*, whom Mr. *Horrox* had desired to observe this transit, and who in mathematical knowledge was inferior to few, very readily complied with his friend's request; but the sky was very unfavourable to him, and he had only one sight of Venus on the Sun's disc, which was about 3 hours 35 minutes by the clock; the Sun then, for the first time, breaking out from the clouds:

at which time he sketched out Venus's situation upon paper, which *Horrox* found to coincide with his own observations.

Mr. *Horrox*, in his treatise on this subject, published by *Hevelius*, and from which almost the whole of this account has been collected, hopes for pardon from the astronomical world, for not making his intelligence more public; but his discovery was made too late. He is desirous, however, in the spirit of a true philosopher, that other astronomers were happy enough to observe it, who might either confirm or correct his observations. But such confidence was reposed in the tables at that time, that it does not appear that this transit of Venus was observed by any besides our two ingenious countrymen, who prosecuted their astronomical studies with such eagerness and precision, that they must very soon have brought their favourite science to a degree of perfection unknown at those times. But unfortunately Mr. *Horrox* died on the 3d of *January* 1640-1, about the age of 25, just after he had put the last hand to his treatise, intitled *Venus in Sole visa*, in which he shews himself to have had a more accurate knowledge of the dimensions of the solar system than his learned commentator *Hevelius*.—*So far the Annual Register*.

In the year 1691*, Dr. HALLEY gave in a paper upon the transit of Venus (See *Lowthorpe*'s Abridgment of Philosophical Transactions, page 434.), in which he observes, from the tables then in use, that Venus returns to a conjunction with the Sun in her ascending node in a period of 18 years, wanting 2 days 10 hours $52\frac{1}{4}$ minutes; but that in the second conjunction she will have got 24′ 41″ farther to the south than in the preceding. That after a period of 235 years 2 hours 10 minutes 9 seconds, she returns to a conjunction more to the north by 11′ 33″; and after 243 years, wanting 43 minutes in a point more

* See the *Connoissance des Temps*, for *A. D.* 1761.

to the south by 13′ 8″. But if the second conjunction be in the year next after leap-year, it will be a day later.

The intervals of the conjunctions at the descending node are somewhat different. The second happens in a period of 8 years, wanting 2 days 6 hours 55 minutes, Venus being got more to the north by 19′ 58″. After 235 years 2 days 8 hours 18 minutes, she is 9′ 21″ more southerly: only, if the first year be a bissextile, a day must be added. And after 243 years 0 days 1 hour 23 minutes, the conjunction happens 10′ 37″ more to the north; and a day later, when the first year was bissextile. It is supposed as in the old style, that all the centurial years are bissextiles.

Hence, Dr. Halley finds the years in which a transit may happen at the ascending node, in the month of *November* (old style) to be these—918, 1161, 1396, 1631, 1639, 1874, 2109, 2117: and the transit in the month of *May* (old style) at the descending node, to be in these years—1048, 1283, 1518, 1526, 1761, 1769, 1996, 2004.

In the first case, Dr. Halley makes the visible inclination of Venus's orbit to be 9° 5′, and her horary motion on the Sun 4′ 7″. In the latter, he finds her visible inclination to be 8′ 28″, and her horary motion 4′ 0″. In either case, the greatest possible duration of a transit is 7 hours 56 minutes.

Dr. Halley could even then conclude, that if the interval in time between the two interior contacts of Venus with the Sun could be measured to the exactness of a second, in two places properly situate, the Sun's parallax might be determined within its 500dth part.—But several years after, he explained this affair more fully, in a paper concerning the transit of Venus in the year 1761; which was published in the Philosophical Transactions, and of which the third of the preceding articles is a translation; the original having been written in *Latin* by the Doctor.

ARTICLE VIII.

Containing a short account of some observations of the transit of Venus, A. D. 1761. June 6th, *new style; and the distances of the planets from the Sun, as deduced from those observations.*

Early in the morning, when every astronomer was prepared for observing the transit, it unluckily happened, that both at *London* and the Royal Observatory at *Greenwich*, the sky was so overcast with clouds, as to render it doubtful whether any part of the transit should be seen:—and it was 38 minutes 21 seconds past 7 o'clock (apparent time) at *Greenwich*, when the Rev. Mr. *Bliss*, our Astronomer Royal, first saw Venus on the Sun; at which instant, the centre of Venus preceded the Sun's centre by 6′ 18″.9 of right ascension, and was south of the Sun's centre by 11′ 42″.1 of declination.—From that time to the beginning of egress, the Doctor made several observations, both of the difference of right ascension and declination of the centres of the Sun and Venus; and at last found the beginning of egress, or instant of the internal contact of Venus with the Sun's limb, to be at 8 hours 19 minutes 0 seconds apparent time. From the Doctor's own observations, and those which were made at *Shirburn* by another gentleman, he has computed, that the mean time at *Greenwich* of the ecliptical conjunction of the Sun and Venus was at 51 minutes 20 seconds after five o'clock in the morning; that the place of the Sun and Venus was ♊ *(Gemini)* 15° 36′ 33″; and that the geocentric latitude of Venus was 9′ 44″.9 south.—Her horary motion from the Sun 3′ 57″.13 retrograde;—and the angle then formed by the axis of the equator, and the axis of the ecliptic, was 6° 9′ 34″, decreasing hourly 1 minute of a degree.—By the mean of three good observations, the diameter of Venus on the Sun was 58″.

Mr. *Short* made his observation at *Savile-House* in *London*, 30 seconds in time west from *Greenwich*, in presence of his Royal Highness the Duke of *York*, accompanied by their Royal Highnesses Prince *William*, Prince *Henry*, and Prince *Frederick*.—He first saw Venus on the Sun through flying clouds, at 46 minutes 37 seconds after 5 o'clock; and at 6 hours 15 minutes 12 seconds he measured the diameter of Venus 59″.8.—He afterward found it to be 58″.9 when the sky was more favourable.—And, through a reflecting telescope of two feet focus, magnifying 140 times, he found the internal contact of Venus with the Sun's limb to be at 8 hours 18 minutes 21⅓ seconds, apparent time; which, being reduced to the apparent time at *Greenwich*, was 8 hours 18 minutes 51⅓ seconds: so that his time of seeing the contact was 6⅔ seconds sooner (in absolute time) than the instant of its being seen at *Greenwich*.

Messrs. *Ellicott* and *Doland* observed the internal contact at *Hackney*, and their time of seeing it, reduced to the time at *Greenwich*, was at 8 hours 18 minutes 36 seconds, which was 4 seconds sooner in absolute time than the contact was seen at *Greenwich*.

Mr. *Canton*, in *Spittle-Square*, *London*, 4′ 11″ west of *Greenwich* (equal to 16 seconds 44 thirds of time), measured the Sun's diameter 31′ 38″ 24‴, and the diameter of Venus on the Sun 58″; and by observation found the apparent time of the internal contact of Venus with the Sun's limb to be at 8 hours 18 minutes 41 seconds; which, by reduction, was only 2¼ seconds short of the time at the Royal Observatory at *Greenwich*.

The Reverend Mr. *Richard Haydon*, at *Leskeard*, in *Cornwall* (16 minutes 10 seconds in time west from *London*, as stated by Dr. *Bevis*) observed the internal contact to be at 8 hours 0 minutes 20 seconds, which by reduction was 8 hours 16 minutes

30 seconds at *Greenwich:* so that he must have seen it 2 minutes 30 seconds sooner in absolute time than it was seen at *Greenwich*—a difference by much too great to be occasioned by the difference of parallaxes. But by a memorandum of Mr. *Haydon*'s some years before, it appears that he then supposed his west longitude to be near two minutes more; which brings his time to agree within half a minute of the time at *Greenwich;* to which the parallaxes will very nearly answer.

At *Stockholm* observatory, latitude 59° 20½′ north, and longitude 1 hour 12 minutes east from *Greenwich*, the whole of the transit was visible; the total ingress was observed by Mr. *Wargentin* to be at 3 hours 39 minutes 23 seconds in the morning, and the beginning of egress at 9 hours 30 minutes 8 seconds; so that the whole duration between the two internal contacts, as seen at that place, was 5 hours 50 minutes 45 seconds.

At *Torneo* in *Lapland* (1 hour 27 minutes 28 seconds east of *Paris*) Mr. *Hellant*, who is esteemed a very good observer, found the total ingress to be at 4 hours 3 minutes 59 seconds; and the beginning of egress to be 9 hours 54 minutes 8 seconds.—So that the whole duration between the two internal contacts was 5 hours 50 minutes 9 seconds.

At *Hernosand* in *Sweden* (latitude 60° 38′ north, and longitude 1 hour 2 minutes 12 seconds east of *Paris*), Mr. *Gister* observed the total ingress to be at 3 hours 38 minutes 26 seconds; and the beginning of egress to be at 9 hours 29 minutes 21 seconds.—The duration between these two internal contacts 5 hours 50 minutes 56 seconds.

Mr. *De La Lande*, at *Paris*, observed the beginning of egress to be at 8 hours 28 minutes 26 seconds apparent time—But Mr. *Ferner* (who was then at *Constans*, 14½″ west of the Royal Observatory at *Paris*) observed the beginning of egress to be at 8 hours 28 minutes 29 seconds true time,

The equation, or difference between the true and apparent time, was 1 minute 54 seconds.—The total ingress, being before the Sun rose, could not be seen.

At *Tobolsk* in *Siberia*, Mr. *Chappe* observed the total ingress to be at 7 hours 0 minutes 28 seconds in the morning, and the beginning of egress to be at 49 minutes 20¼ seconds after 12 at noon.—So that the whole duration of the transit between the internal contacts was 5 hours 48 minutes 52¼ seconds, as seen at that place; which was 2 minutes 3½ seconds less than as seen at *Hernosand* in *Sweden*.

At *Madras*, the Reverend Mr. *Hirst* observed the total ingress to be at 7 hours 47 minutes 55 seconds apparent time in the morning; and the beginning of egress at 1 hour 39 minutes 38 seconds past noon. The duration between these two internal contacts was 5 hours 51 minutes 43 seconds.

Professor *Mathenci* at *Bologna* observed the beginning of egress to be at 9 hours 4 minutes 58 seconds.

At *Calcutta* (latitude 22° 30′ north, nearly 92° east longitude from *London*) Mr. *William Magee* observed the total ingress to be at 8 hours 20 minutes 58 seconds in the morning, and the beginning of egress to be at 2 hours 11 minutes 34 seconds in the afternoon. The duration between the two internal contacts 5 hours 50 minutes 36 seconds.

At the *Cape of Good Hope* (1 hour 13 minutes 35 seconds east from *Greenwich*) Mr. *Mason* observed the beginning of egress to be at 9 hours 39 minutes 50 seconds in the morning.

All these times are collected from the observers' accounts, printed in the Philosophical Transactions for the year 1762 and 1763, in which there are several other accounts that I have not transcribed.—The instants of Venus's total exit from the Sun are likewise mentioned; but they are here left out, as not of any use for finding the Sun's parallax.

Whoever compares these times of the internal contacts, as given in by different observers, will find such difference among them, even those which were taken upon the same spot, as will shew, that the instant of either contact could not be so accurately perceived by the observers as Dr. HALLEY thought it could; which probably arises from the difference of people's eyes, and the different magnifying powers of those telescopes through which the contacts were seen.—If all the observers had made use of equal magnifying powers, there can be no doubt but that the times would have more nearly coincided; since it is plain, that supposing all their eyes to be equally quick and good, they whose telescopes magnified most, would perceive the point of internal contact soonest, and of the total exit latest.

Mr. *Short* has taken an incredible deal of pains in deducing the quantity of the Sun's parallax, from the best of those observations which were made both in *Britain* and abroad: and finds it to have been 8″.52 on the day of the transit, when the Sun was very nearly at his greatest distance from the Earth; and consequently 8″.65 when the Sun is at his mean distance from the Earth.—And indeed, it would be very well worth every curious person's while to purchase the second part of Volume LII. of the Philosophical Transactions for the year 1763; even if it contained nothing more than Mr. *Short*'s paper on that subject.

The log. sine (or tangent) of 8″.65 is 5.6219140, which being subtracted from the radius 10.0000000, leaves remaining the logarithm 4.3780860, whose number is 23882.84; which is the number of semidiameters of the Earth that the Sun is distant from it.—And this last number, 23882.84, being multiplied by 3985, the number of *English* miles contained in the Earth's semidiameter, gives 95,173,127 miles for the Earth's mean distance from the Sun.—But because it is impossible, from the nicest obser-

vations of the Sun's parallax, to be sure of its true distance from the Earth within 100 miles, we shall at present, for the sake of round numbers, state the Earth's mean distance from the Sun at 95,173,000 *English* miles.

And then, from the numbers and analogies in § 11 and 14 of this Dissertation, we find the mean distances of all the rest of the planets from the Sun in miles to be as follows:--Mercury's distance, 36, 841, 468; Venus's distance, 68,891,486; Mar's distance, 145,014,148; Jupiter's distance, 494,990,976; and Saturn's distance, 907,956,130.

So that by comparing these distances with those in the tables at the end of the chapter on the solar system*, it will be found that the dimensions of the system are much greater than what was formerly imagined: and consequently, that the Sun and the planets (except the Earth) are much larger than as stated in that table.

The semidiameter of the Earth's annual orbit being equal to the Earth's mean distance from the Sun, viz. 95,173,000 miles, the whole diameter is 190,346,000 miles. And since the diameter of a circle is to its circumference as 1 to 3.14159 the circumference of the Earth's orbit is 597,989.090 miles.

And, as the Earth describes this orbit in 365 days 6 hours (or in 8766 hours), it is plain that it travels at the rate of 68,217 miles every hour, and consequently 11,369 miles every minute; so that its velocity in its orbit is at least 142 times as great as the velocity of a cannon-ball, supposing the ball to move through 8 miles in a minute, which it is found to do very nearly;—and at this rate it would take 22 years 228 days for a cannon-ball to go from the Earth to the Sun.

On the 3d of *June*, in the year 1769, Venus will again pass over the Sun's disc, in such a manner,

* Fronting page 72.

as to afford a much easier and better method of investigating the Sun's parallax than her transit in the year 1761 has done.—But no part of *Britain* will be proper for observing that transit, so as to deduce any thing with respect to the Sun's parallax from it, because it will begin but a little before sun-set, and will be quite over before 2 o'clock next morning.—The apparent time of conjunction of the Sun and Venus, according to Dr. HALLEY's tables, will be at 13 minutes past 10 o'clock at night at *London*; at which time the geocentric latitude of Venus will be full 10 minutes of a degree north from the Sun's centre:—and therefore, as seen from the northern parts of the Earth, Venus will be considerably depressed by a parallax of latitude on the Sun's disc; on which account, the visible duration of the transit will be lengthened; and in the southern parts of the Earth she will be elevated by a parallax of latitude on the Sun, which will shorten the visible duration of the transit, with respect to its duration as supposed to be seen from the Earth's centre; to both which affections of duration the parallaxes of longitude will also conspire.—So that every advantage which Dr. HALLEY expected from the last transit will be found in this, without the least difficulty or embarrassment.—It is therefore to be hoped, that neither cost nor labour will be spared in duly observing this transit; especially as there will not be such another opportunity again in less than 105 years afterward.

The most proper places for observing the transit, in the year 1769, is in the northern parts of *Lapland* and the *Solomon Isles* in the great *South-Sea*; at the former of which, the visible duration between the two internal contacts will be at least 22 minutes greater than at the latter, even though the Sun's parallax should not be quite 9″.——If it be 9″ (which is the quantity I had assumed in a delineation of this

transit, which I gave in to the Royal Society before I had heard what Mr. *Short* had made it from the observations on the late transit), the difference of the visible durations, as seen in *Lapland* and in the *Solomon Isles*, will be as expressed in that delineation; and if the Sun's parallax be less than 9″ (as I now have very good reason to believe it is), the difference of durations will be less accordingly.

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